Neutron detectors development

Toward future spallation sources

Bruno Guerard

- MicroStrip gas chambers (MSGC)
- MultiWires gas chambers (MWPC)
- Position sensitive counter tubes

Developments supported by the ILL Millennium program
- large angle coverage banana MWPC
- The Multitube detector
- high resolution 2D detectors (scintillators and He3)

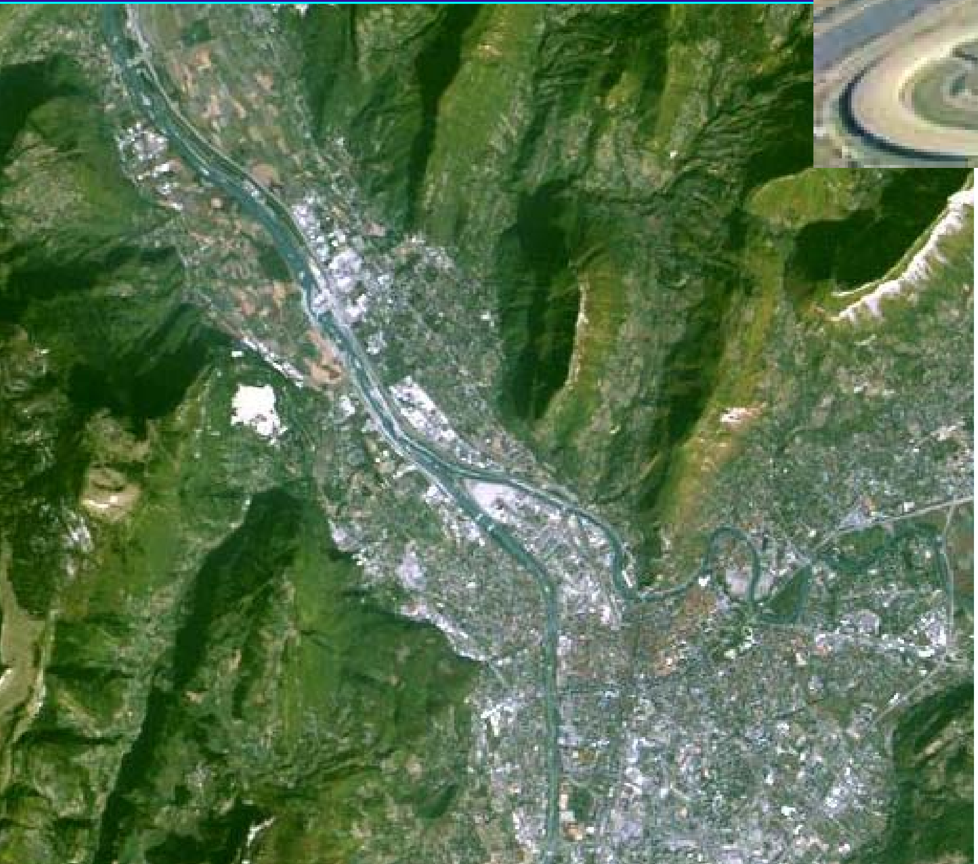
International scientific co-operation

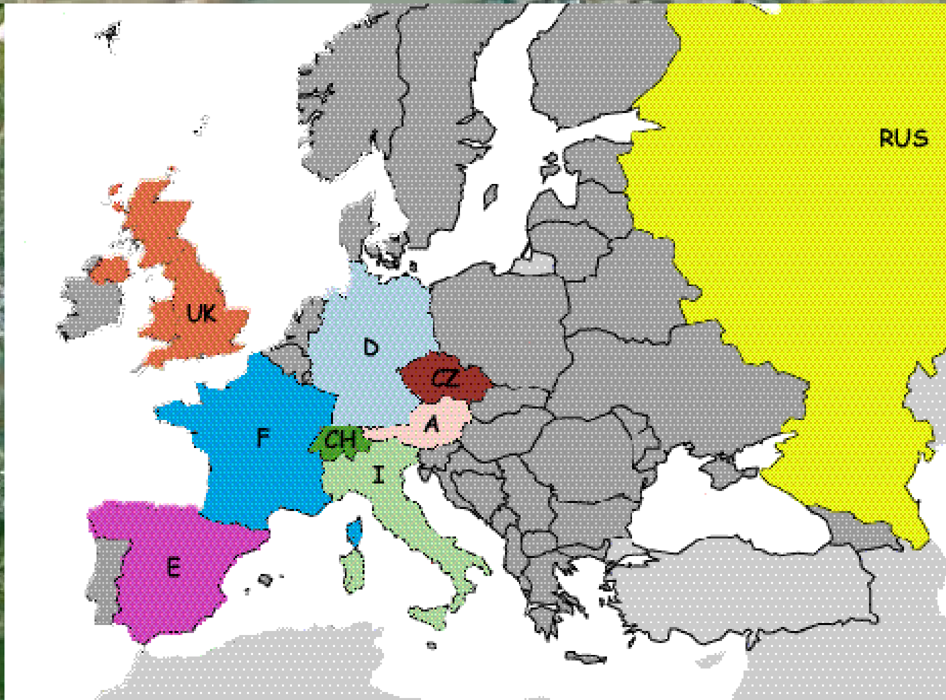
The ILL is operated by its three founder countries:

France 31%
Germany 31%
United Kingdom 26%

In association with its partner countries :

Austria: 1.5%
Spain: 3%
Italy: 3%
Czech Republic:` 0.5%
Russia: 2%
Switzerland: 3.5%





ILL/SDN (Service des Détecteurs de Neutrons)

Jean-Claude Buffet Mechanical design
Gilbert Viande Mechanical design
Michel Gamon Electronician
Fabrice Horst Electronician
Frédéric Millier Electronician
Jean-Francois Clergeau Physicist
Bruno Guerard Physicist
Giuliana Manzin Physicist
Patrick Van Esch Physicist

Fabrication outlines

Gas filling
  outgasing, detection efficiency, position resolution

Electronics
  individual readout versus charge division

Type of detector
  MSGC, MWPC, PSCT, scintillators

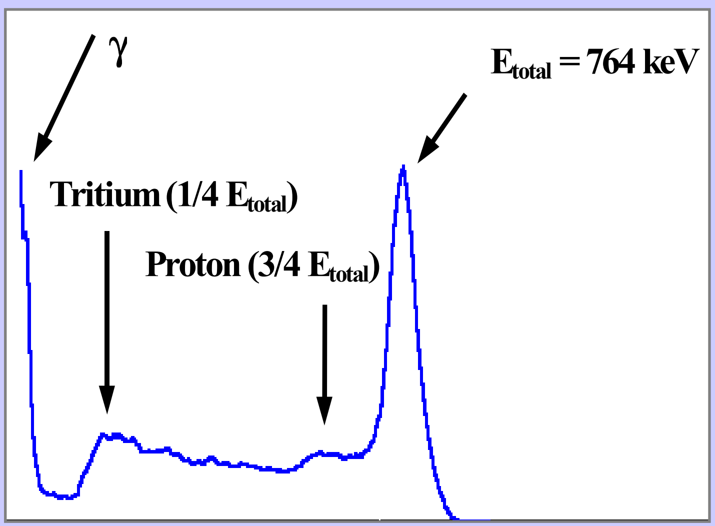
Nuclear reactions for neutron detectors

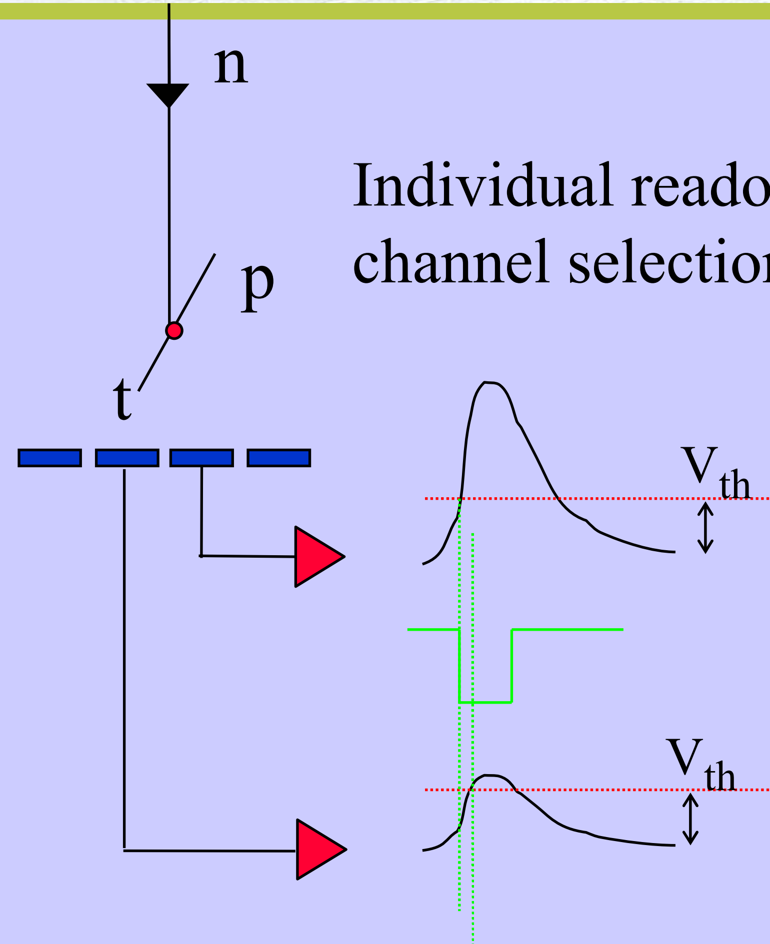
- $n + {}^{3}He \rightarrow {}^{3}H + {}^{1}H + 0.764$ MeV
- $n + {}^{6}Li \rightarrow {}^{4}He + {}^{3}H + 4.79$ MeV
- $n + {}^{10}B \rightarrow {}^{7}Li^{*} + {}^{4}He \quad \rightarrow {}^{7}Li + {}^{4}He + 0.48$ MeV γ +2.3 MeV (93%)
  $\rightarrow {}^{7}Li + {}^{4}He$ +2.8 MeV (7%)
- $n + {}^{155}Gd \rightarrow Gd^{*} \rightarrow \gamma$-ray spectrum $\rightarrow$ conversion electron spectrum
- $n + {}^{157}Gd \rightarrow Gd^{*} \rightarrow \gamma$-ray spectrum $\rightarrow$ conversion electron spectrum
- $n + {}^{235}U \rightarrow$ fission fragments + ~160 MeV
- $n + {}^{239}Pu \rightarrow$ fission fragments + ~160 MeV

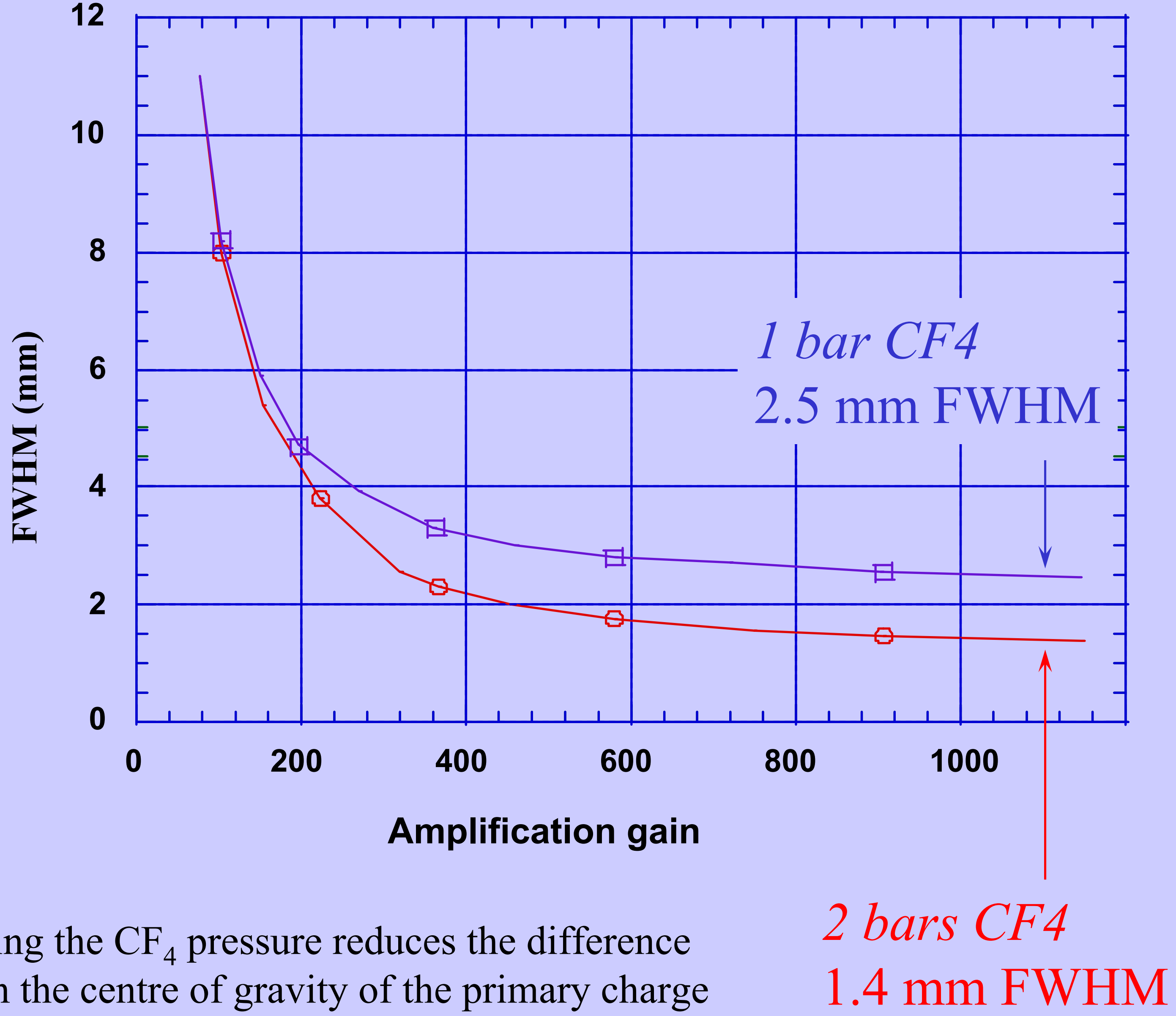
Advantages of ^{3}He detectors
- counting dynamics
- Time resolution
- low sensitivity to γ

Individual readout : channel selection

3He Pulse Height spectrum

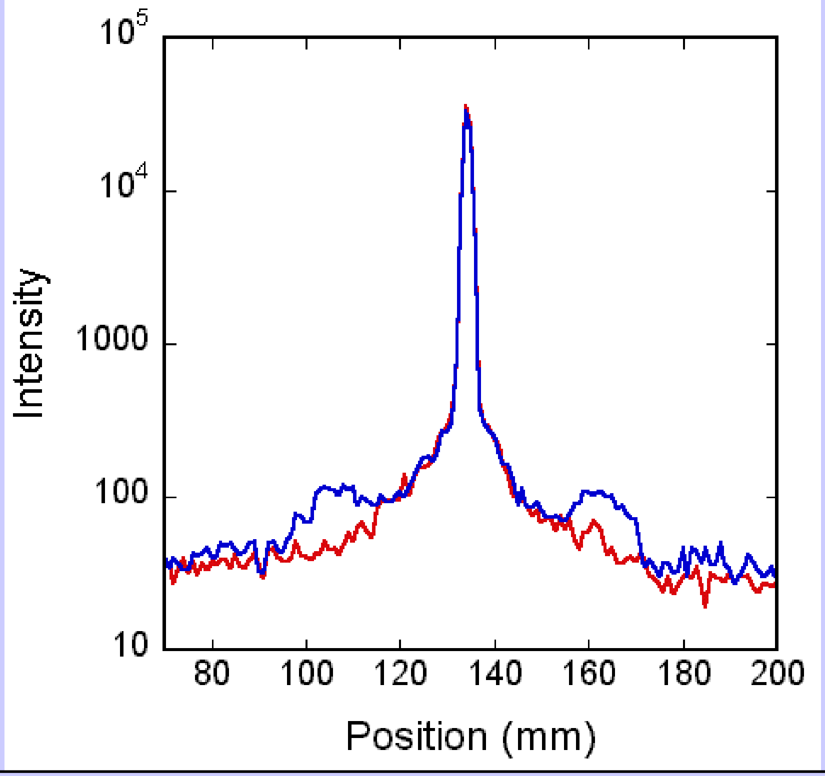


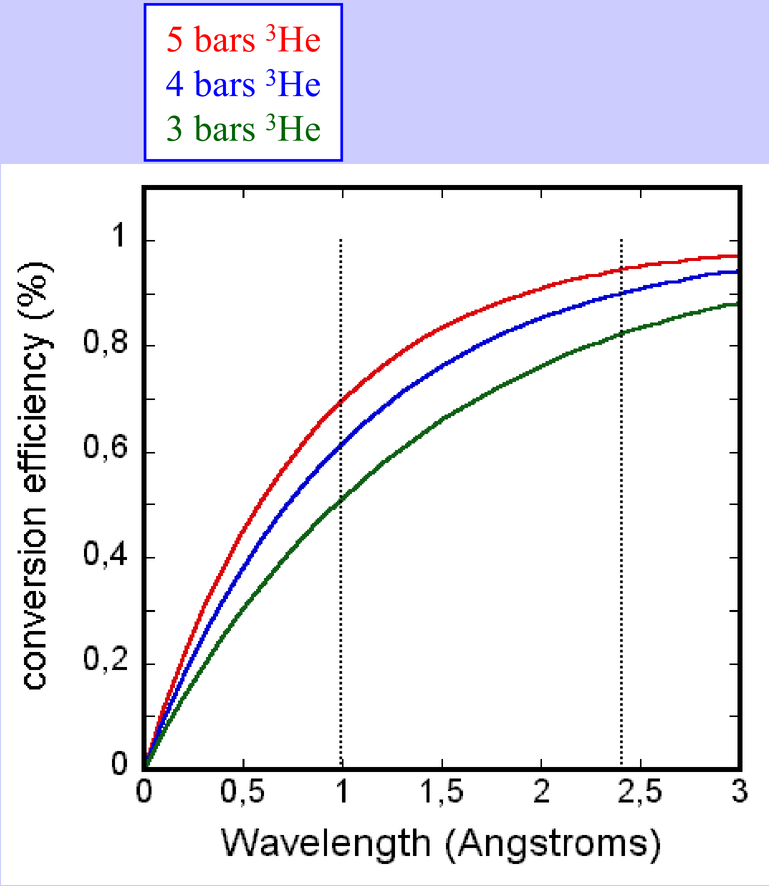




Increasing the CF_4 pressure reduces the difference between the centre of gravity of the primary charge cloud and the point where the neutron interacted.

Detection efficiency and scattering





Scattering & absorption measurement performed with a position sensitive counter tube and a sample of Aluminium (5083) 5 mm thick

measured attenuation : 5.92% (abs. + scatt.)

Calculated absorption : 1.72 %

⇨ scattering = 4.2%

Neutron conversion efficiency

$$\varepsilon = 1 - e^{-gap*\sigma*n}$$

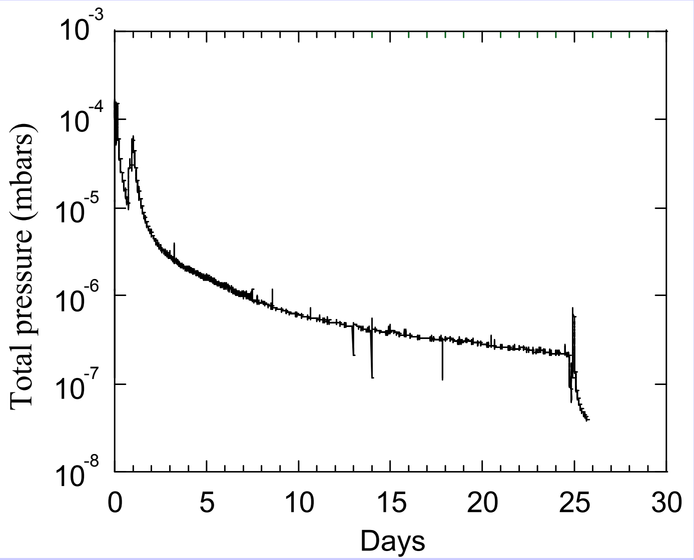
gap = 3 cm; n = density of gas

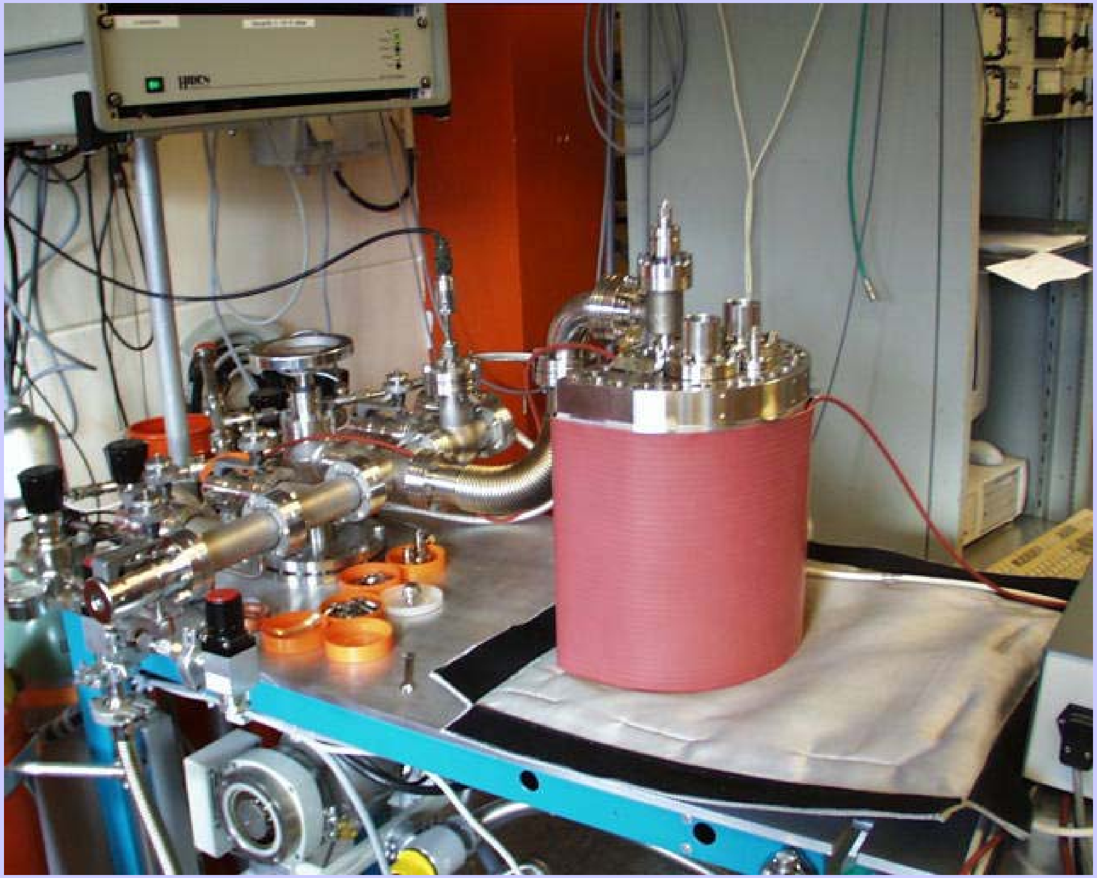
s = absorption cross section

= 5333 barns * λ/1.8

Gas purity

Sealed detectors --> require very pure gas
- Selection of the mechanical components of the detector
- Double O-Ring, or metallic gasket
- heating at 150°C under control of a mass spectrometer.

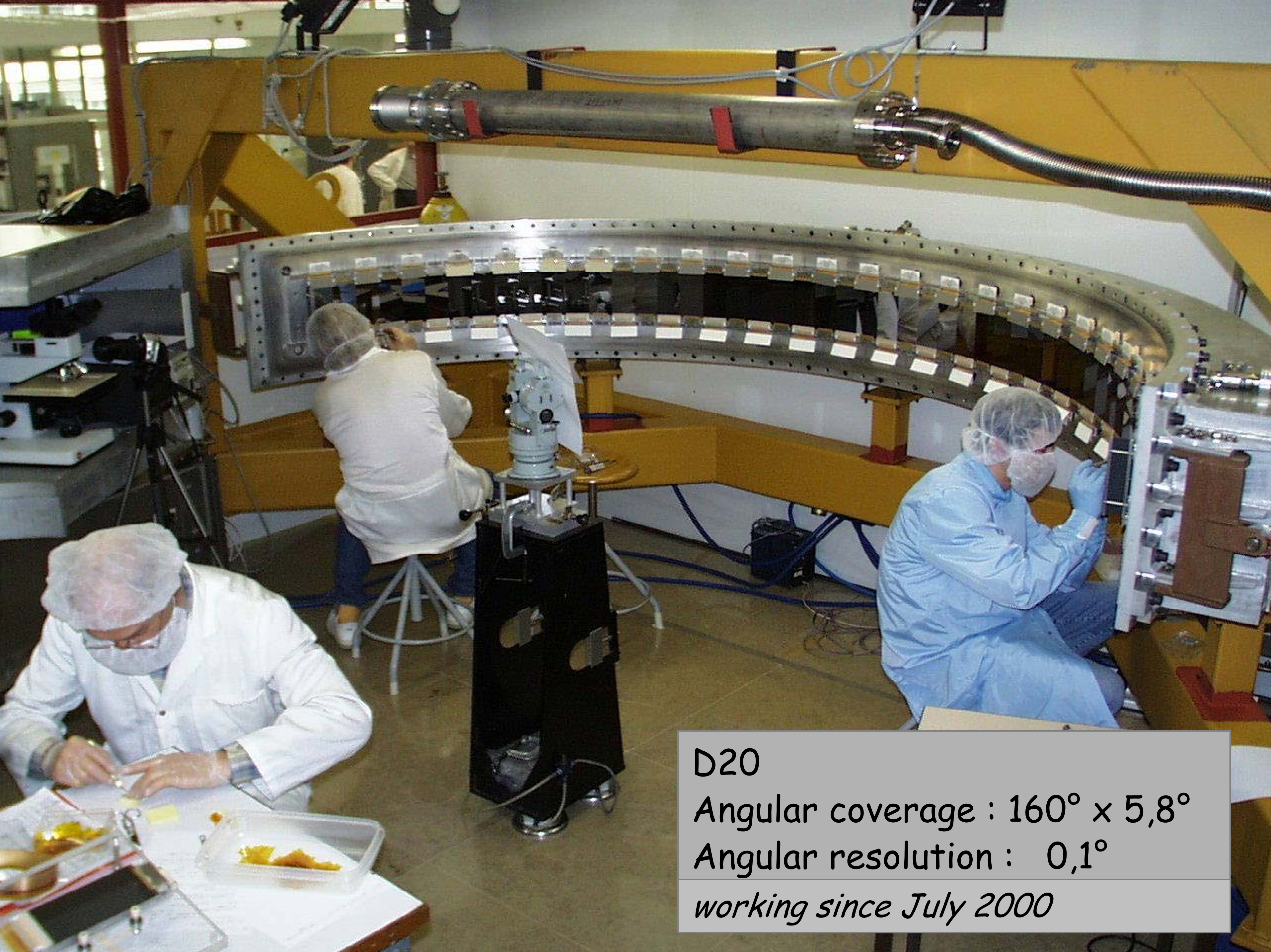




MSGC detectors

Advantages :
- Spatial uniformity

Drawbacks :
- One supplier only (IMT)
- Limited size



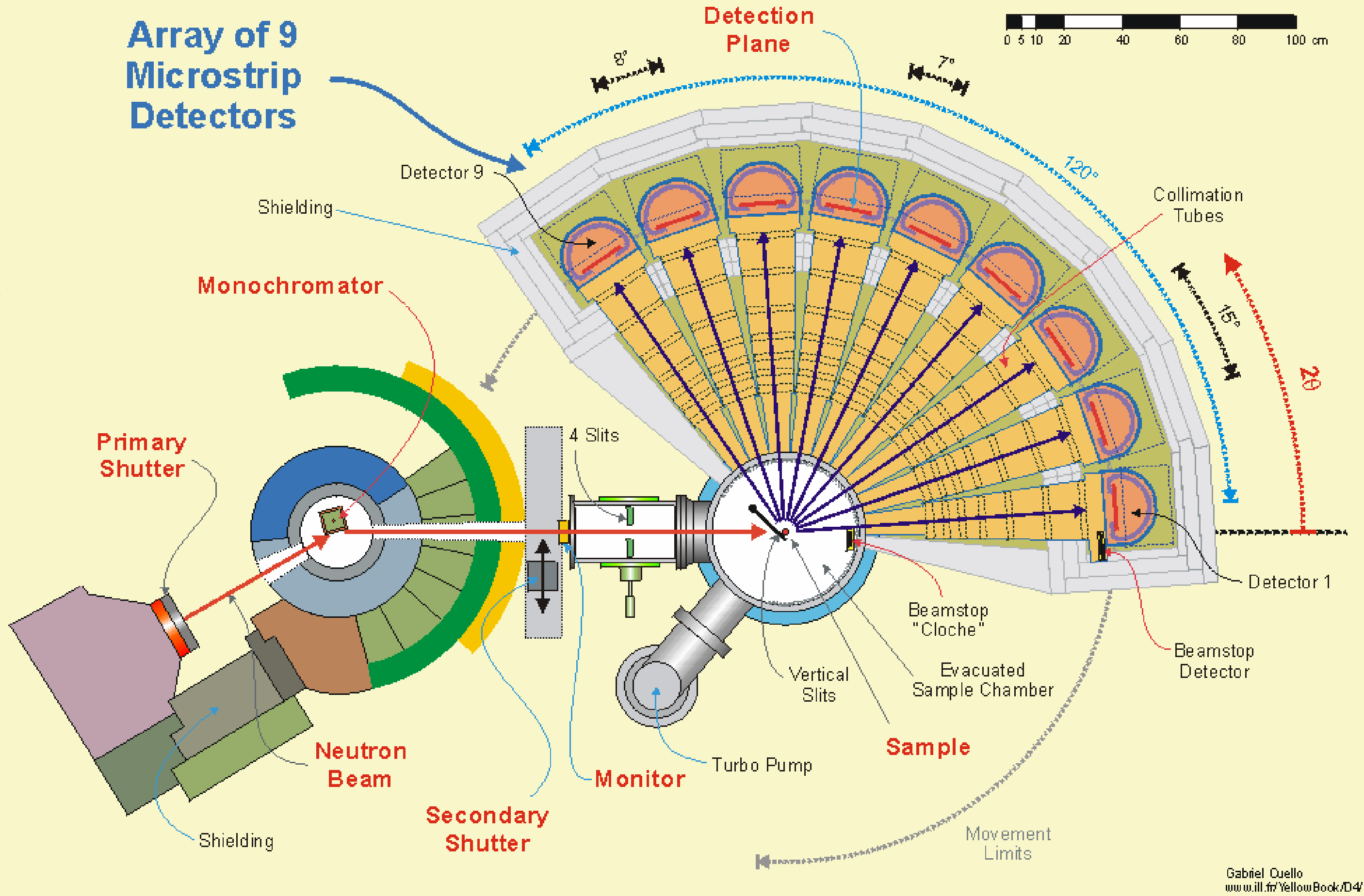
D20

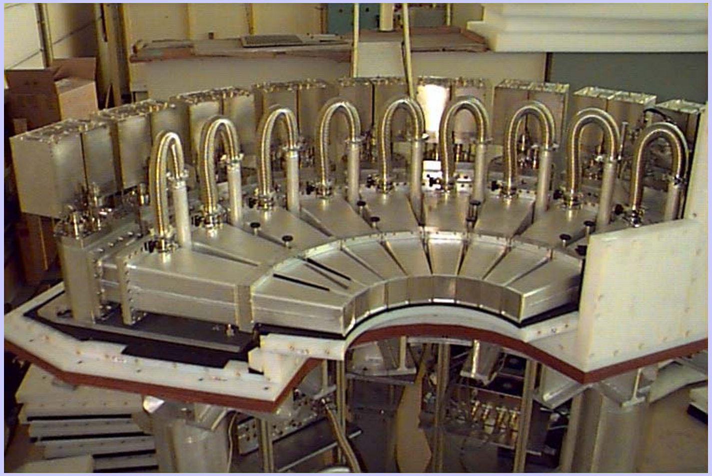
Angular coverage : 160° x 5,8°

Angular resolution : 0,1°

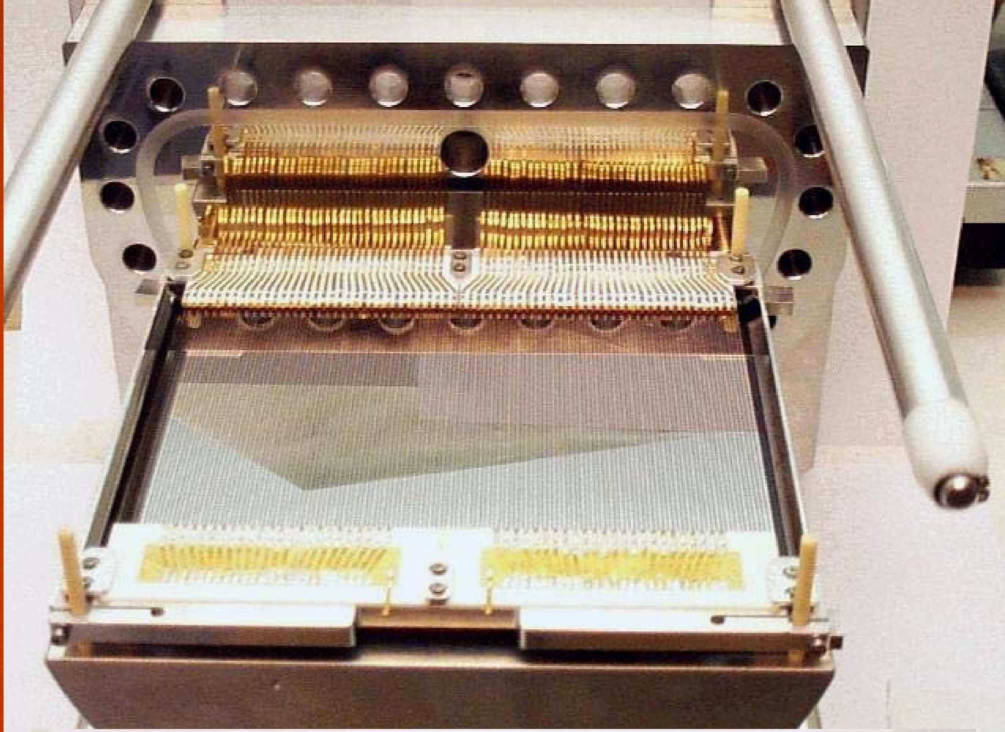
working since July 2000

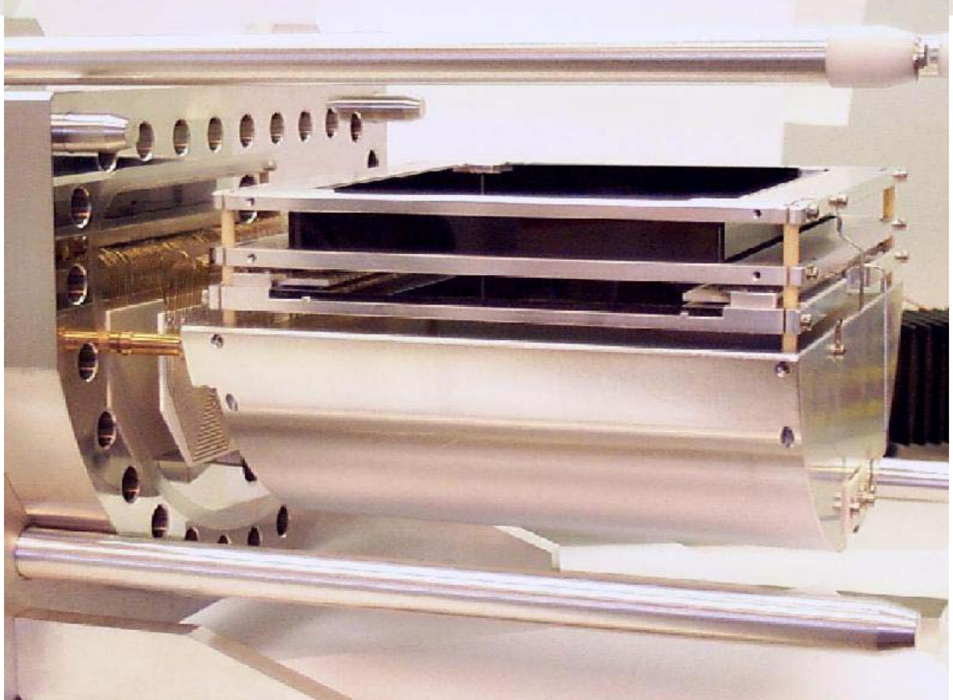
D4C
Modularity & high efficiency

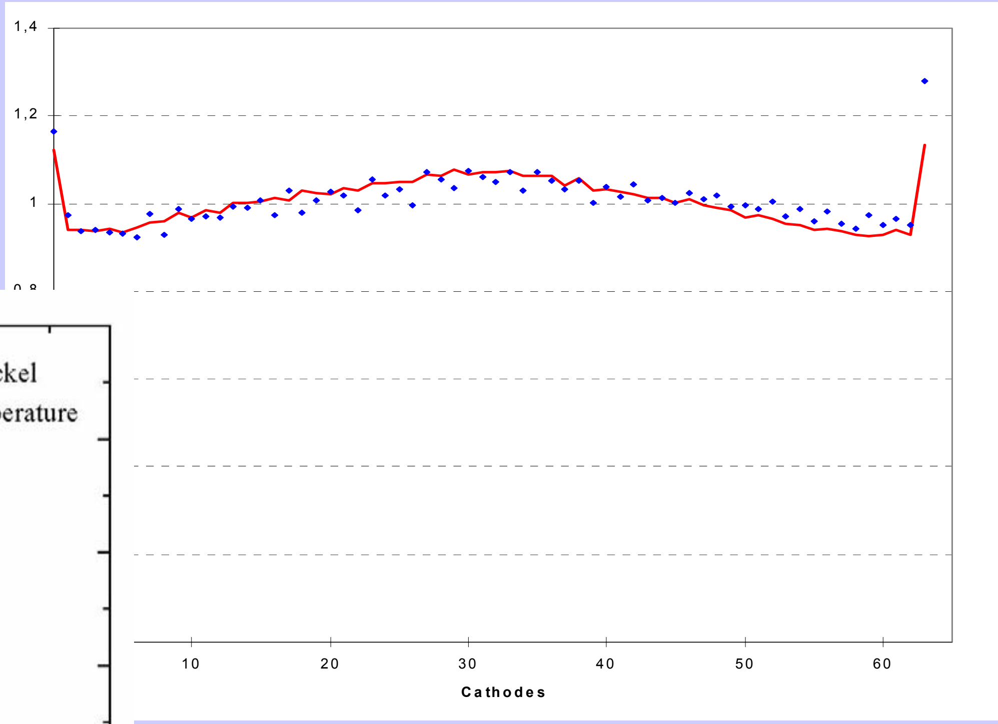


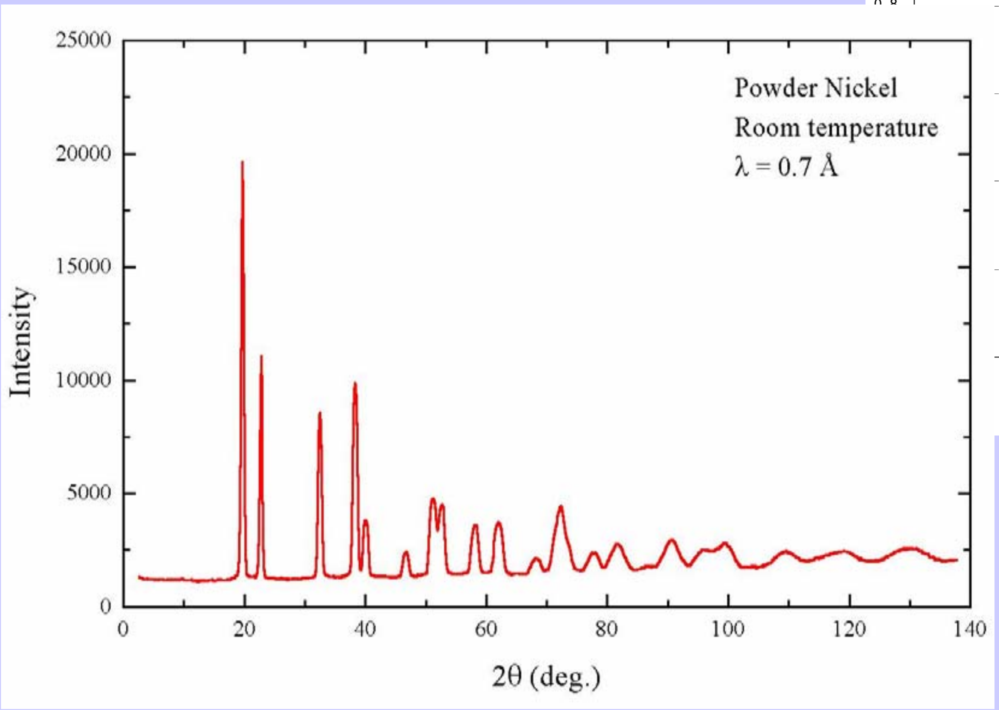


Aperture : 145° (2 scans) x 10 cm height
Position resolution : 2.5 mm
Absorption gap : 30 mm
Gas pressure : 15 bars 3He + 0.3 bar CF4
Detection efficiency : 90% (@ 0.7 angstroms)
Counting rate : 50 kHz/cell



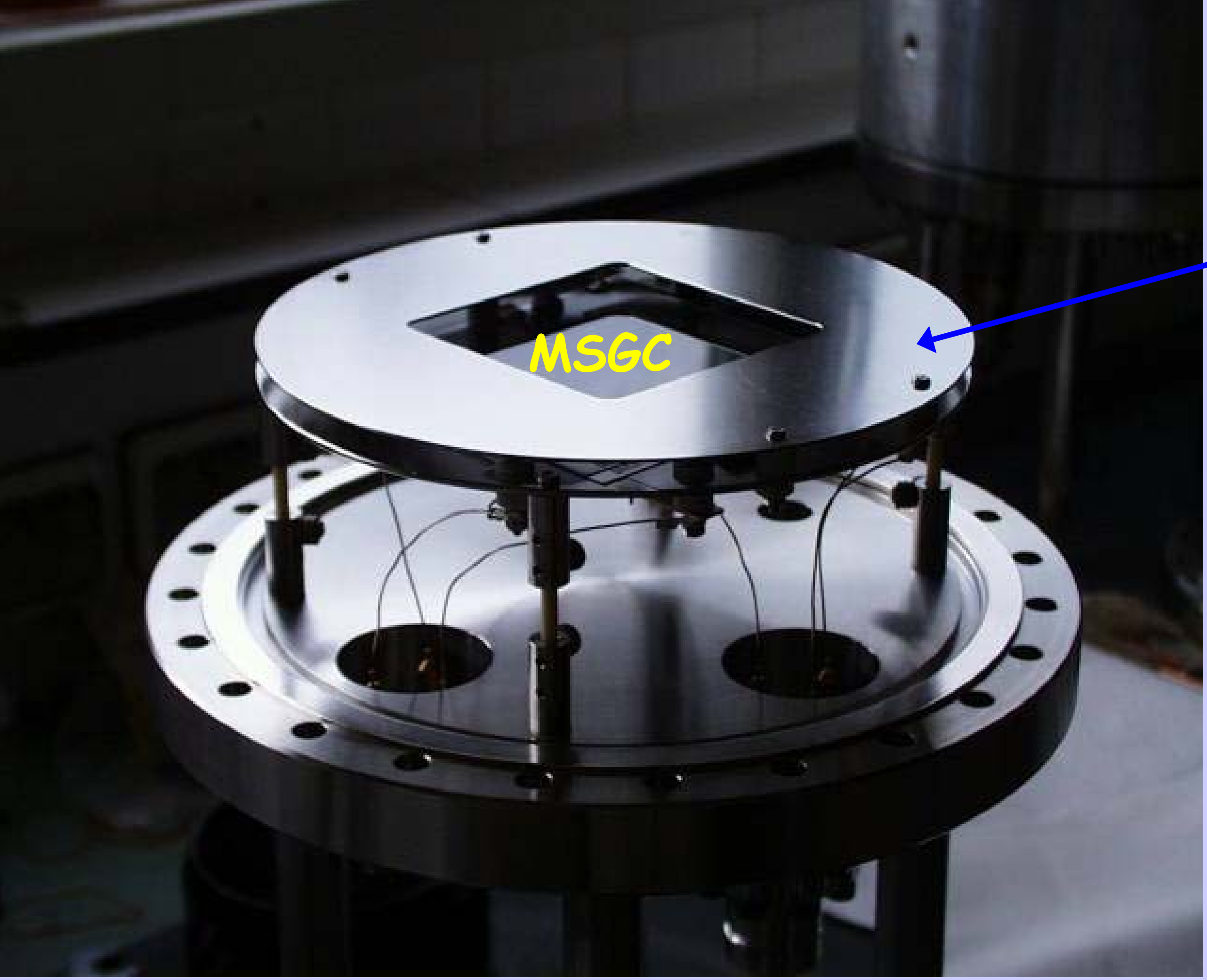






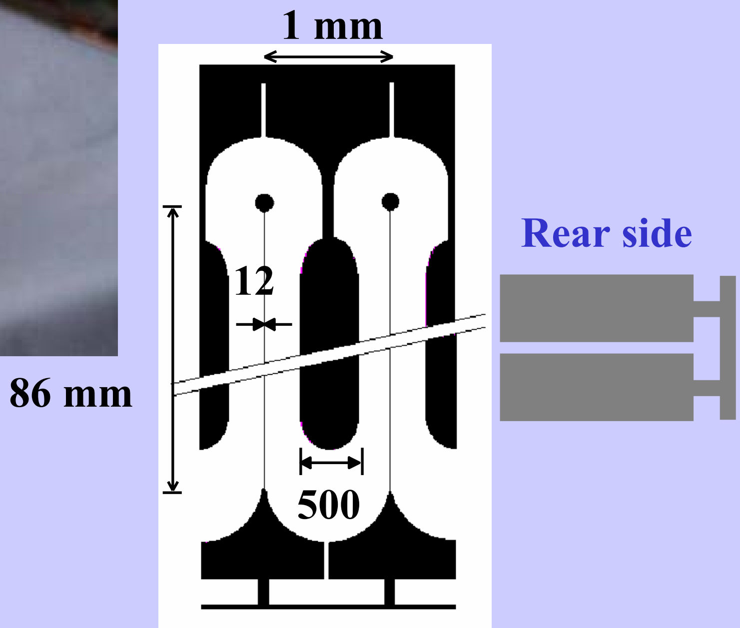
Response with a vanadium sample
Maximum deviation from average :
5% before calibration
1% after calibration

Nickel sample diffraction curve used to calibrate the position of the 9 MSGCs



80 mm x 80 mm x 1 mm

5 detectors working at ILL
the first without interruption since 96



Charge division readout

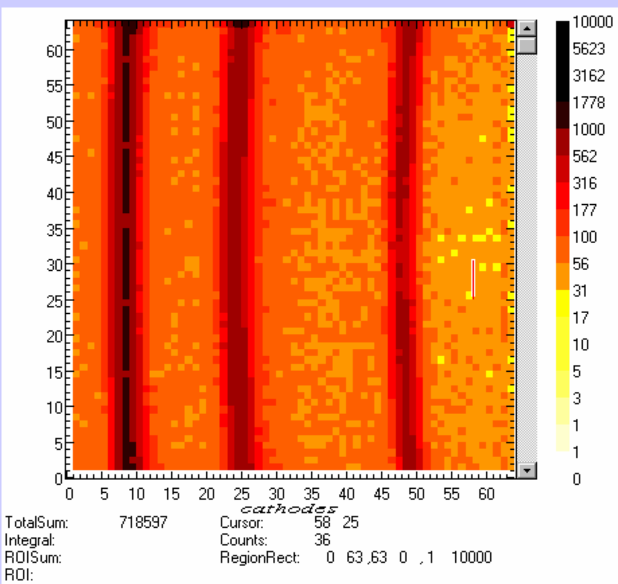
Individual Readout 64x64

Position resolution : 3 mm

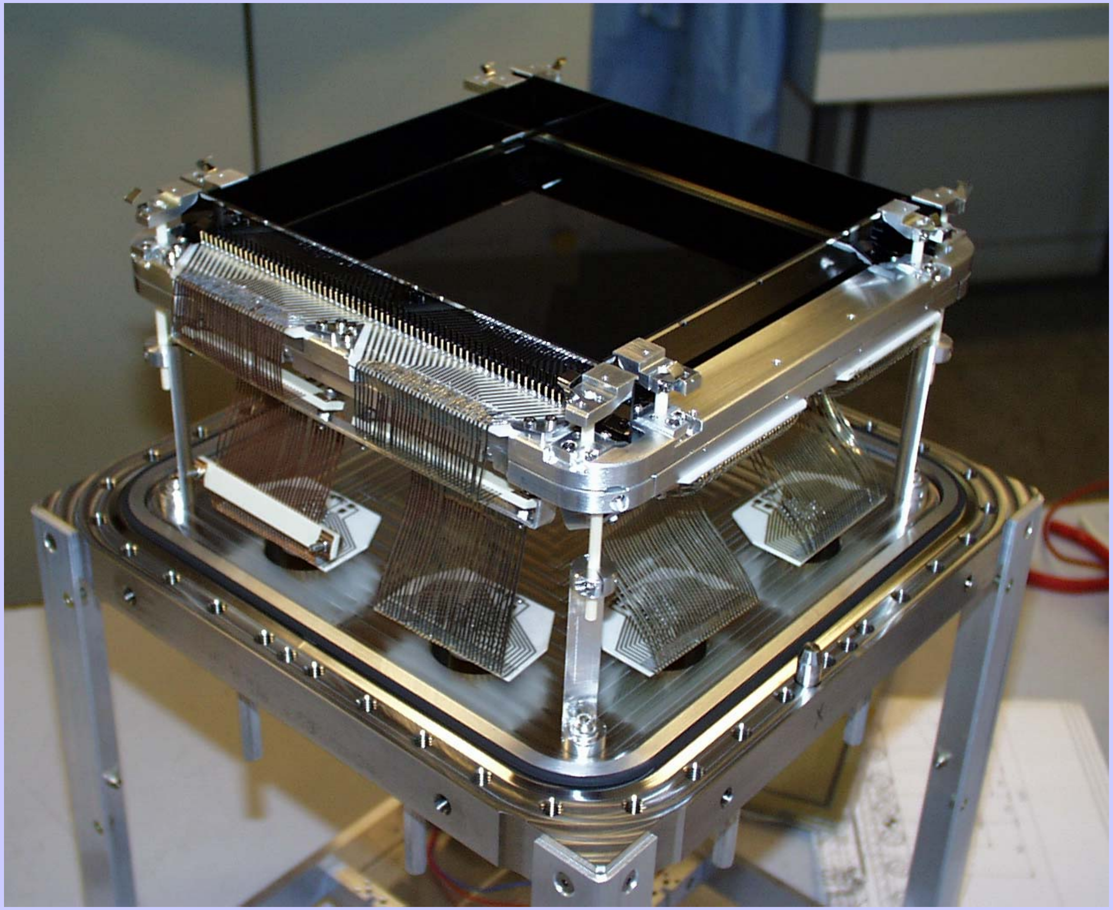
Useful area: 192 mm x 192 mm

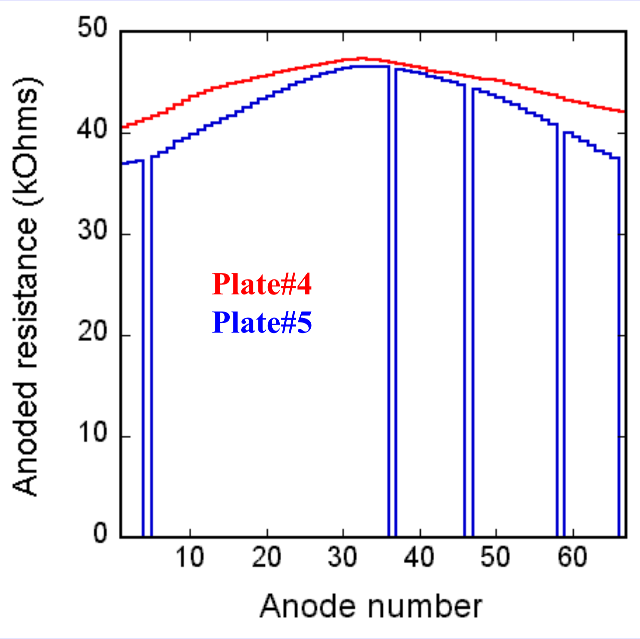
94% efficiency at 2.4 Angstroms

Counting rate : 500 kHz (with
base line restorer amplifiers)



TiO2 powder sample
@ 2.5 Angstroms





Fabrication features

Substrate : S8900 240 mm x 240 mm x 1.5 mm.

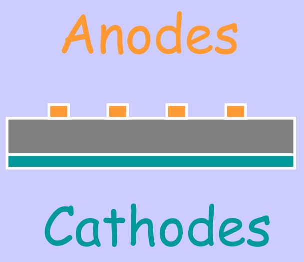
Entrance window : 5 mm aluminium

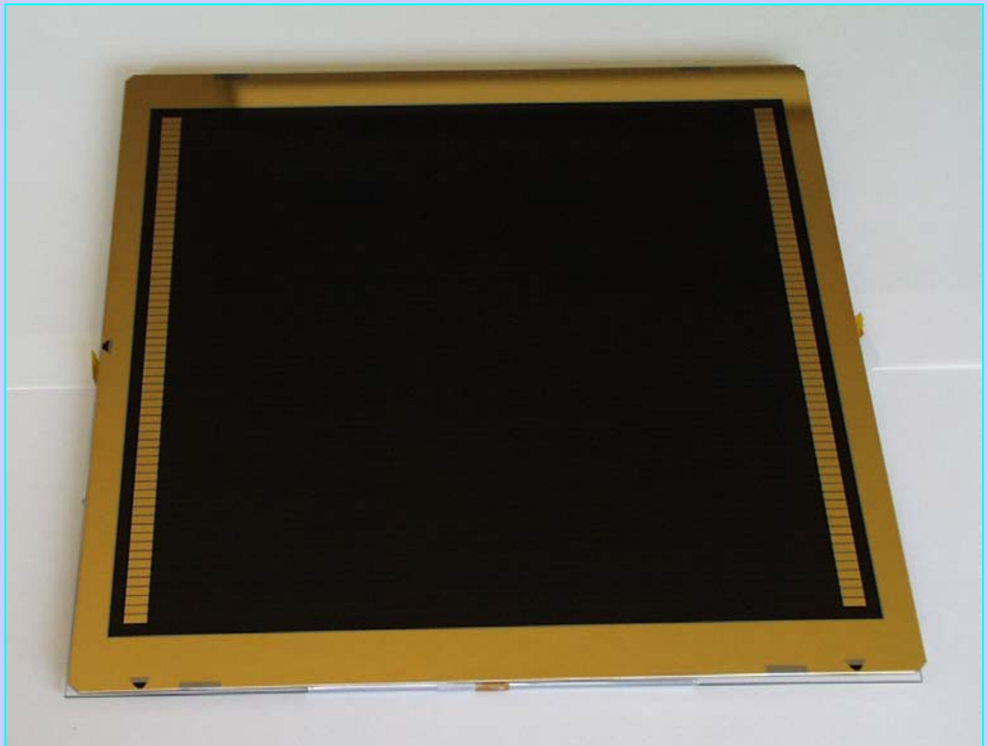
Gas Mixture : 5 bars 3He + 2 bars CF4

working since August 2001

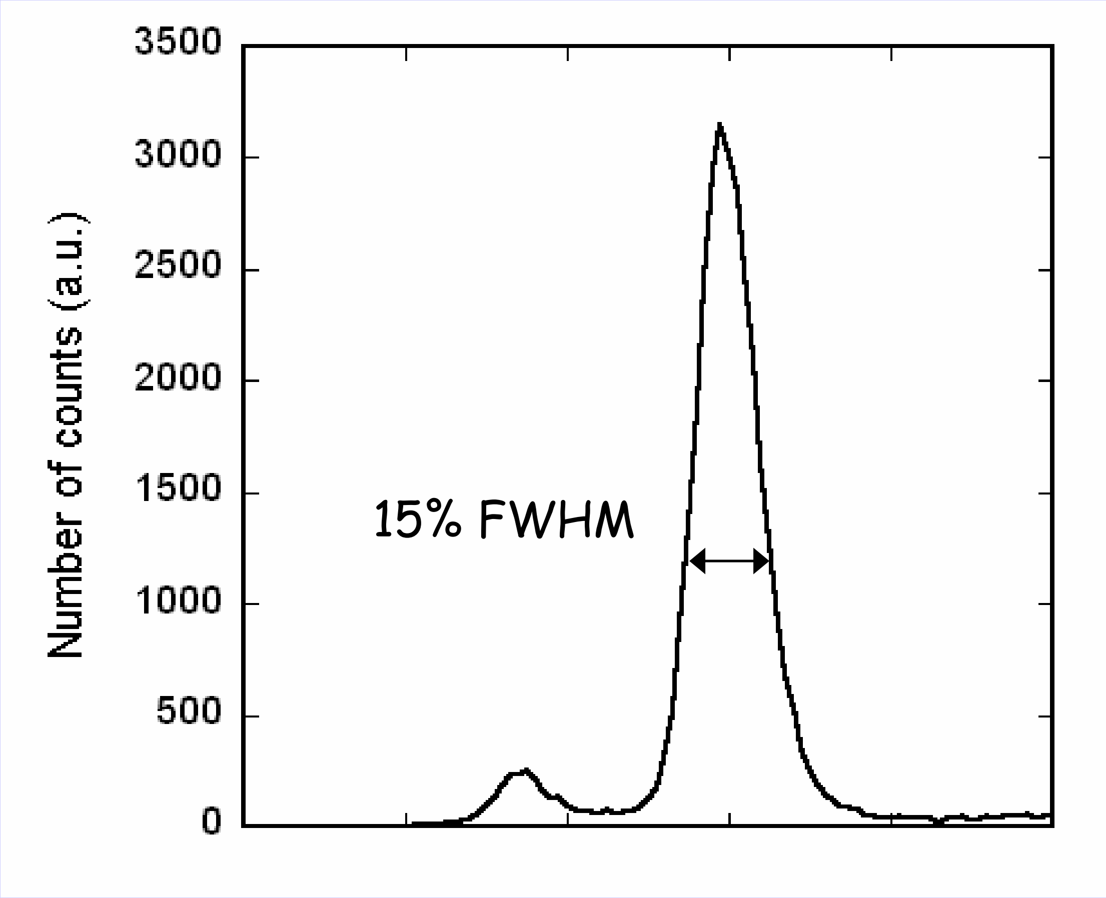
Virtual cathode layout

Higher maximum amplification factor --> more robust
Anode and cathode signals are equal (and of opposite sign)
Double connection of the anodes
--> parallel charge division readout
--> Easy control of anode resistance value
But …. counting rate limitation





X-Rays

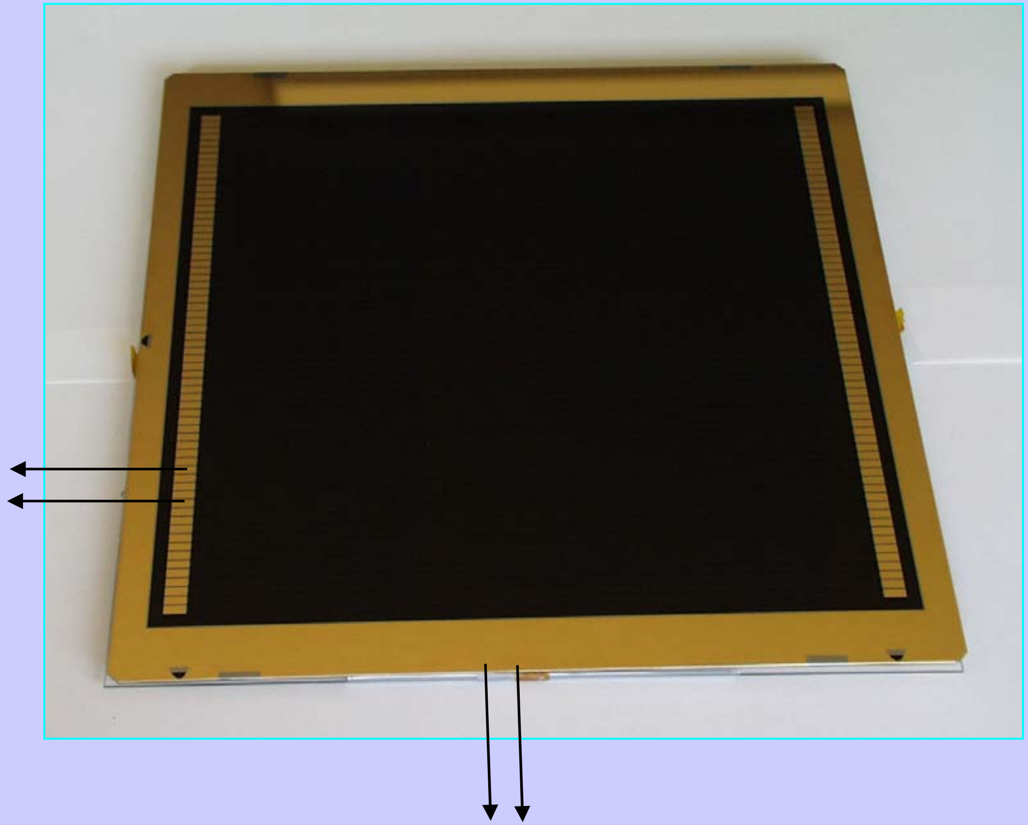


^{55}Fe source pulse height spectrum in Argon:CH4 (90:10)
(source inside the detector vessel)

$G = 10^5$

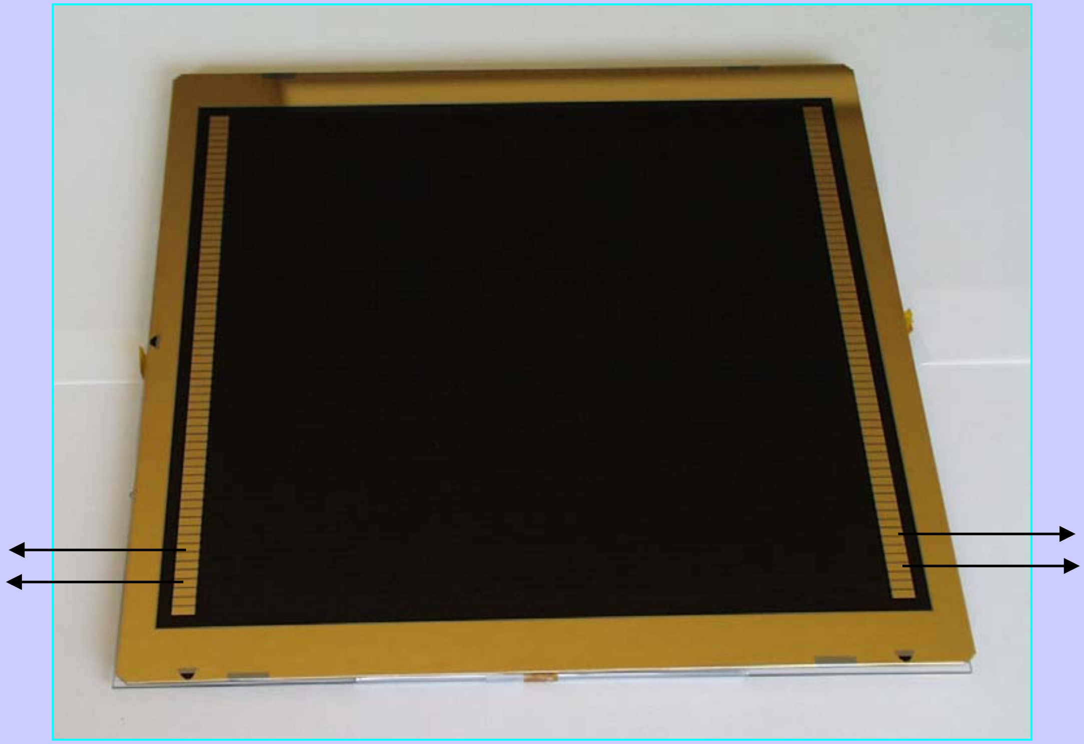
XY individual readout : Dead time & counting limits

1 μs/strip (time development)
100 ns global (XY coincidence)
3 KHz/mm of anode (glass charging)

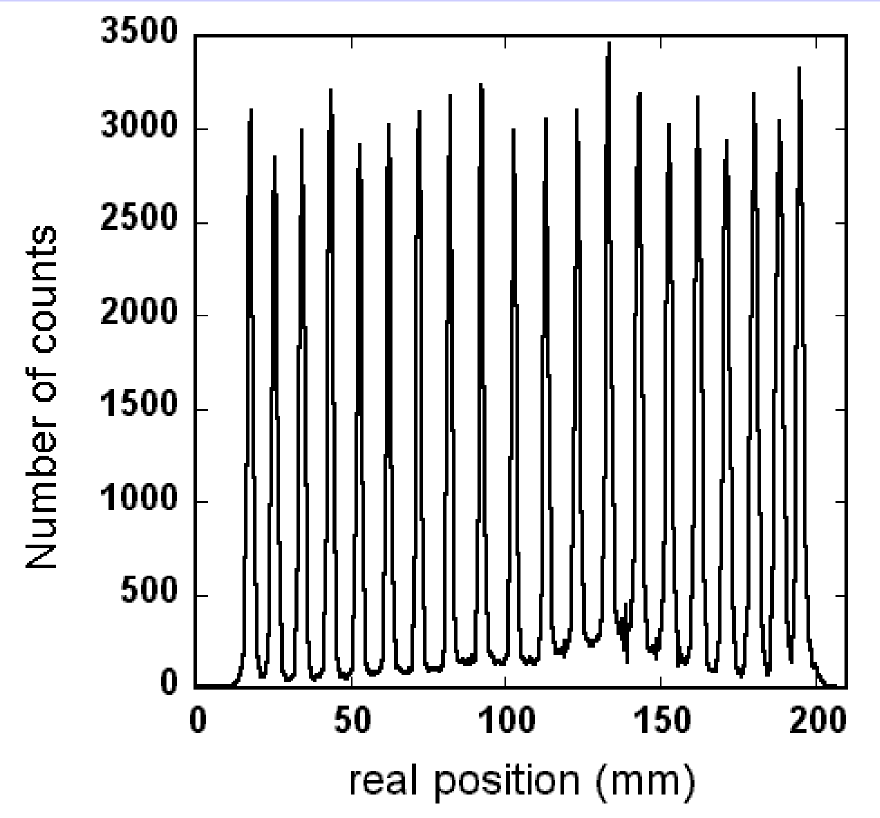


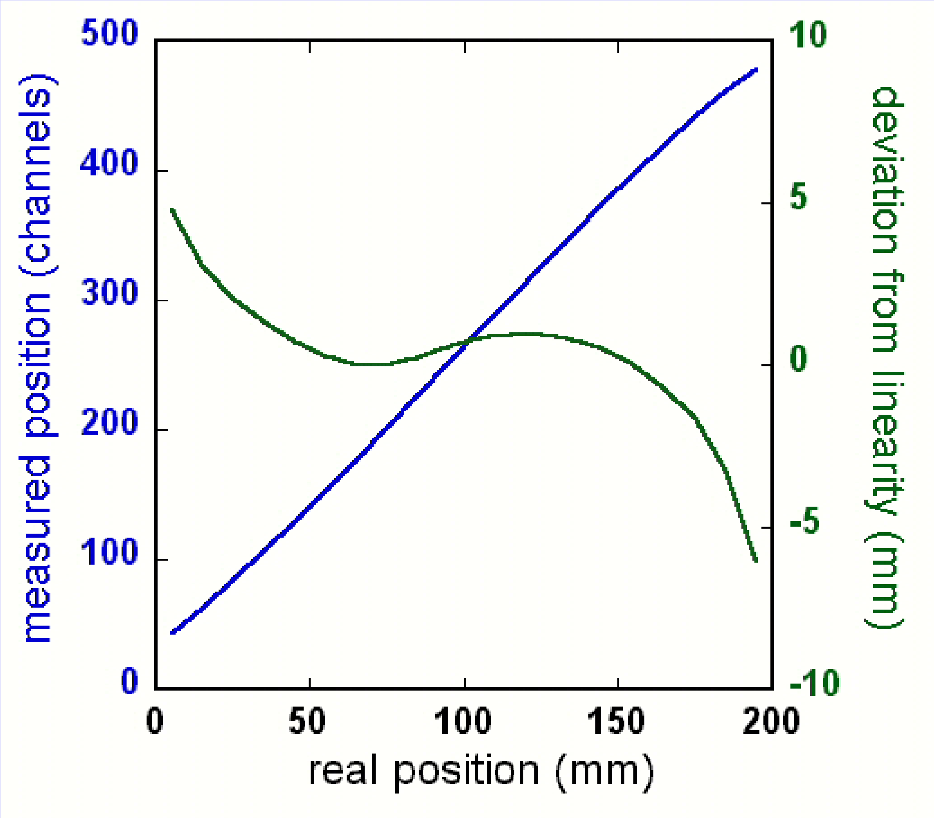
XY charge division along each anode strip

- Improved position resolution in one direction
- No XY coincidence dead time



Charge division along the anodes : position linearity



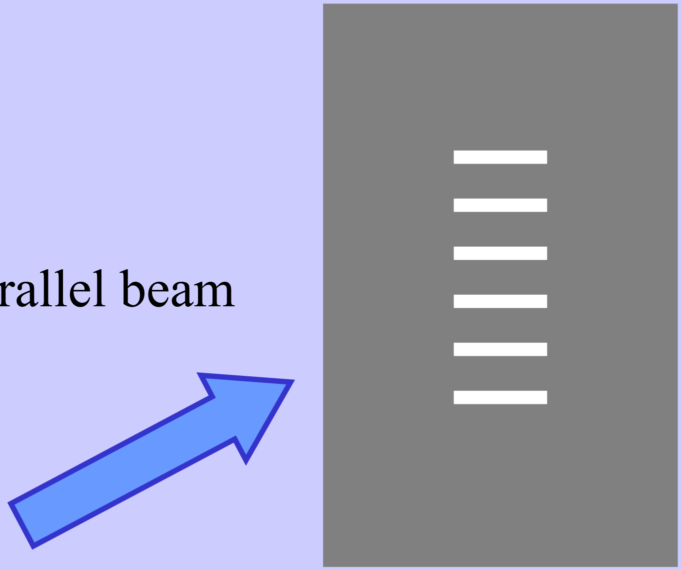


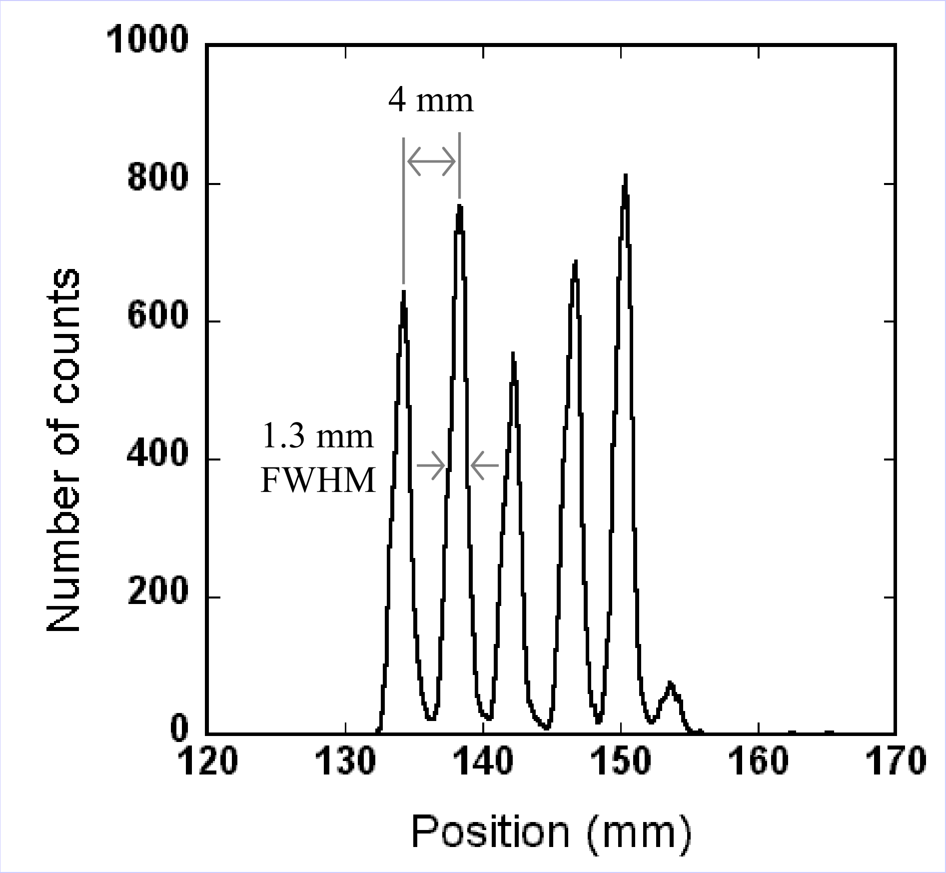
Position resolution

1.3 mm FWHM = limit of the stopping gas (2 bars CF_4)

Cadmium mask

Parallel beam





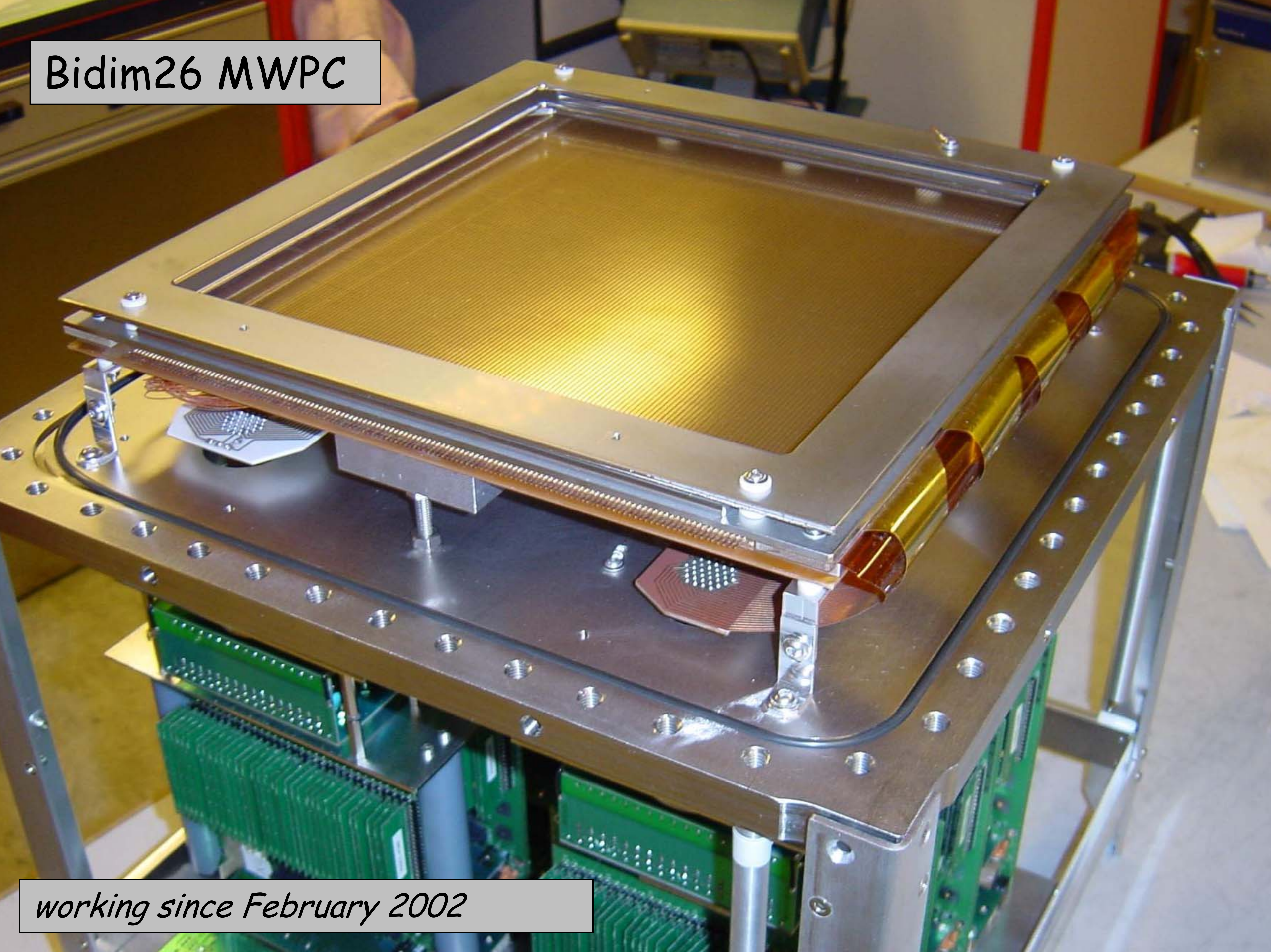
Future work : improve the position resolution and the counting rate

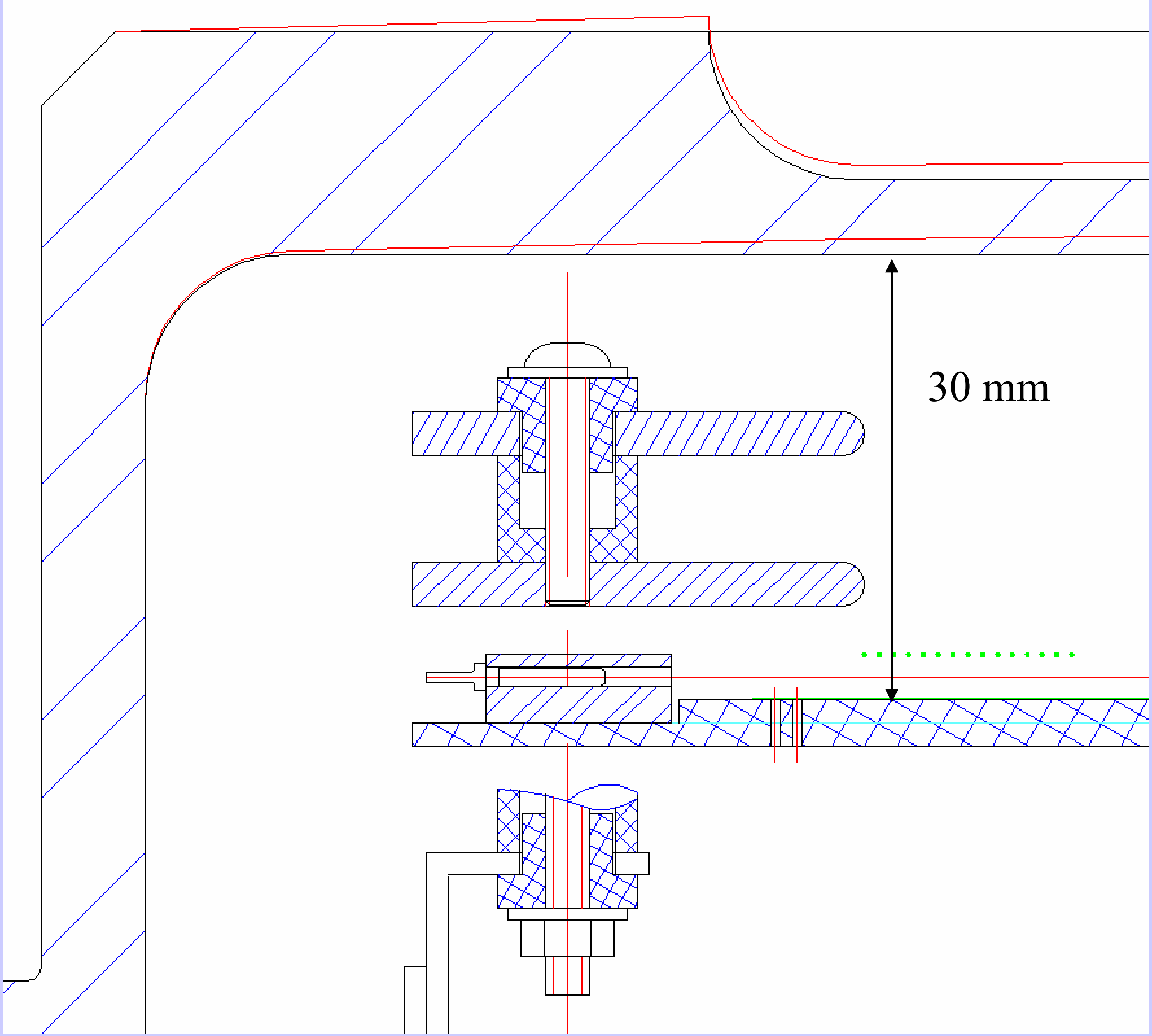
- divide by 5 the substrate thickness (requires a gluing of the glass on a metallic reinforcement) --> 0.3 mm

- multiply by 5 the number of anodes --> 0.6 mm pitch

- add floating electrodes between anodes to help discharging the glass surface

MWPC detectors


Bidim26 MWPC
working since February 2002


30 mm

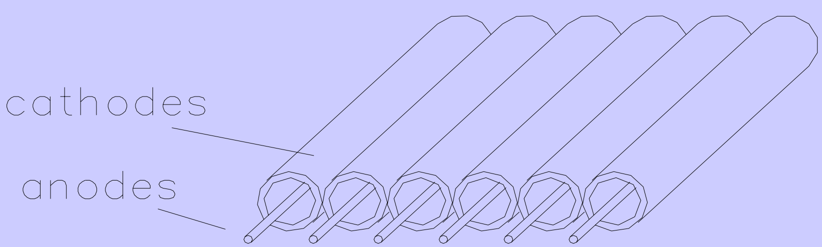
Bidim26 MWPC

PSCT

(Position sensitive counter tubes)

Actual D22 detector

2 orthogonal frames of sensing wires with a pitch of 7.5 mm.
A coincidence time of 200 ns between the 2 frames limits the counting performance of this type of detector to about 500 kHz (200 kHz with all contributions)

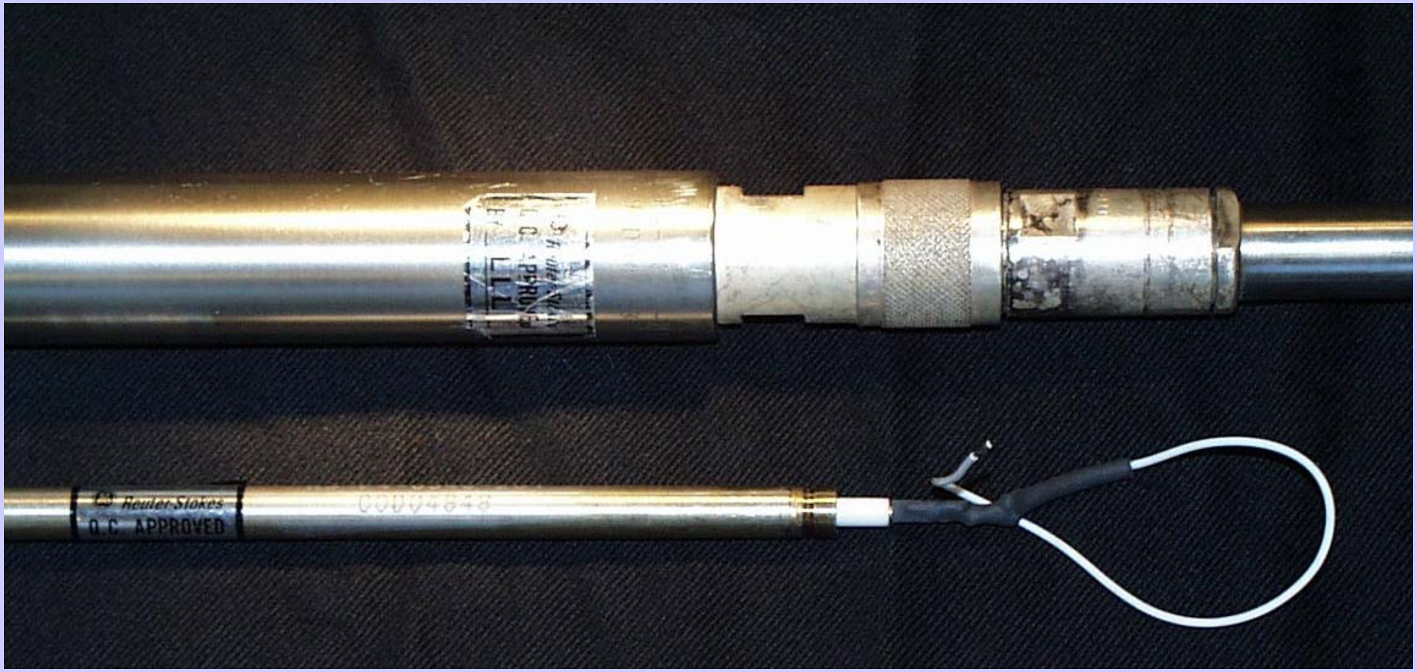


SANS_2MHz

By Measuring the signals on both ends of a resistive wire centred in a tube, the position of each neutron can be determined along the tube without affecting the measurement on the other tubes. This principle has been adopted to improve the counting rate on the future D22 detector.

Small diameter PSCT

8 mm diameter, 1 m long, and 15 bars of He3.



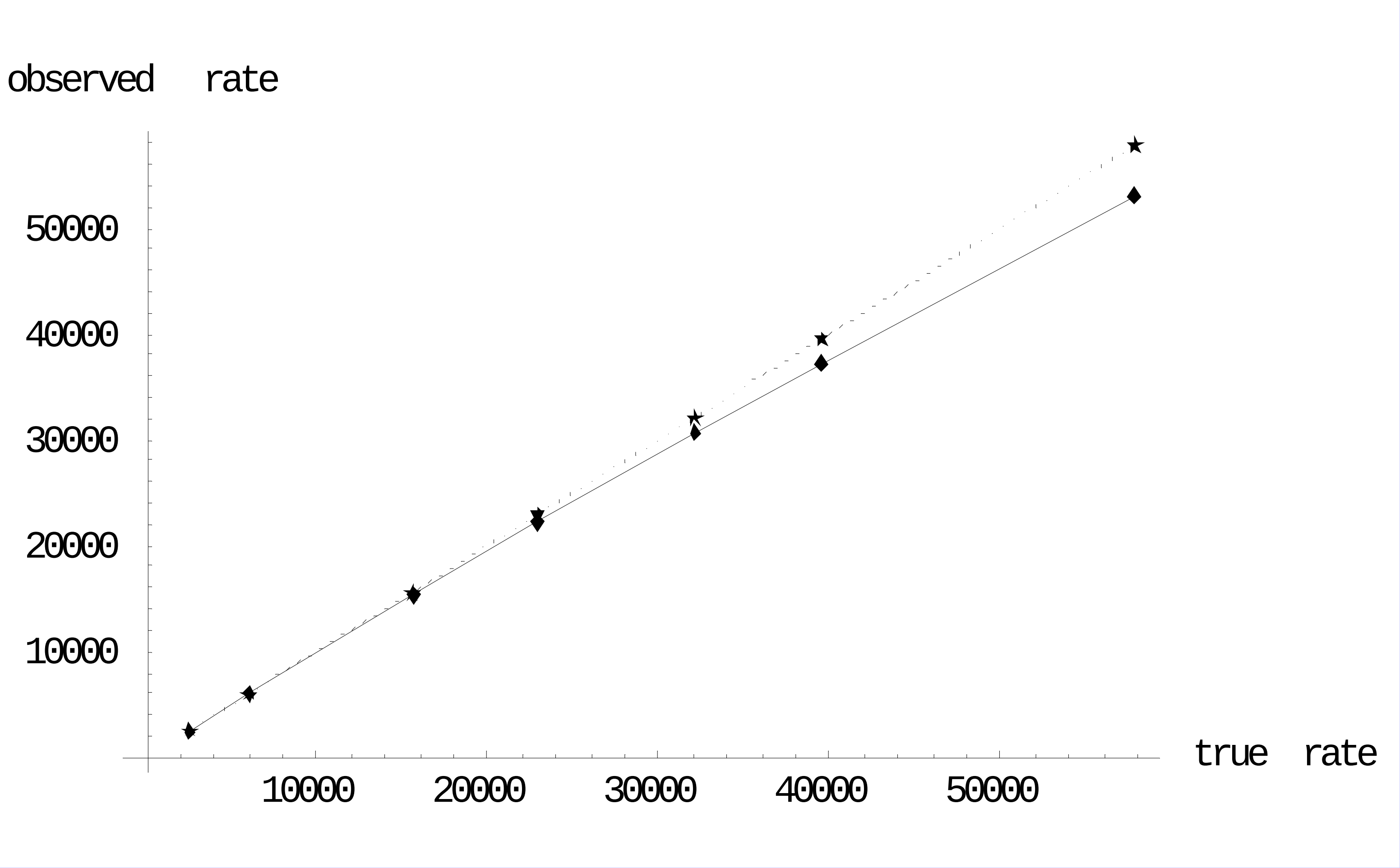
Electronics

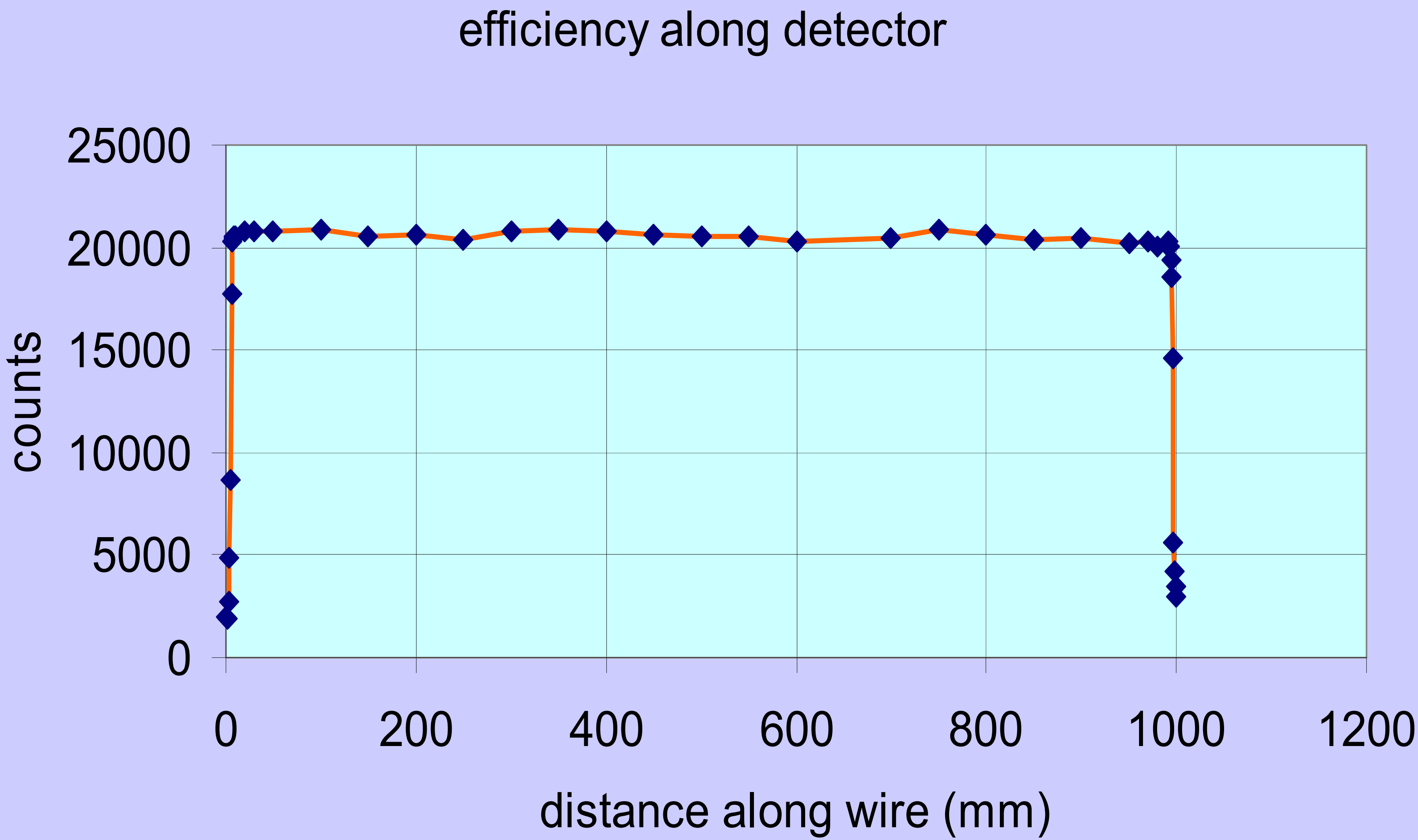
Low noise amplifier, pulse shaping, base line restorer circuit, followed by a charge division processing card which converts the two analogue signals into the position.

Position resolution = 6 mm (3 mm at very high gain)

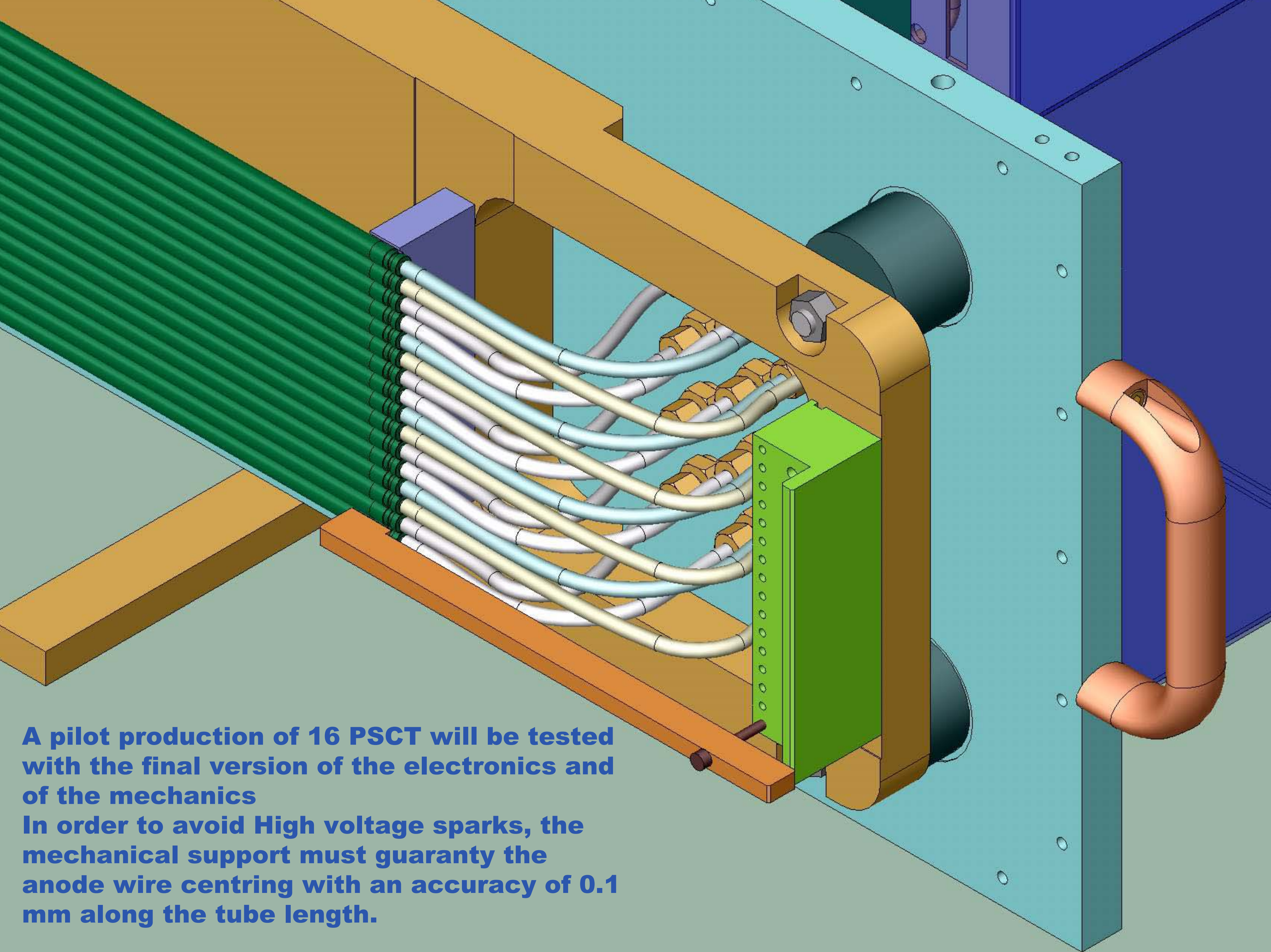
Counting rate

From the measured rate versus true rate relationship, the dead time of one PSCT associated with its electronics is estimated at 1.4 μsec. If we define a limit of 10% counting loss, the maximum counting rate of one PSCT is then 70 kHz. For an uniform irradiation, this value corresponds to 9 MHz for the future assembling of 128 PSCT, a factor of 50 better than the actual detector.





Specification of spatial resolution comfortably met :
6 mm (9 mm at 100 KHz/tube).



A pilot production of 16 PSCT will be tested with the final version of the electronics and of the mechanics
In order to avoid High voltage sparks, the mechanical support must guaranty the anode wire centring with an accuracy of 0.1 mm along the tube length.

MAPS - 16 m2 with 15 x 25 mm resolution

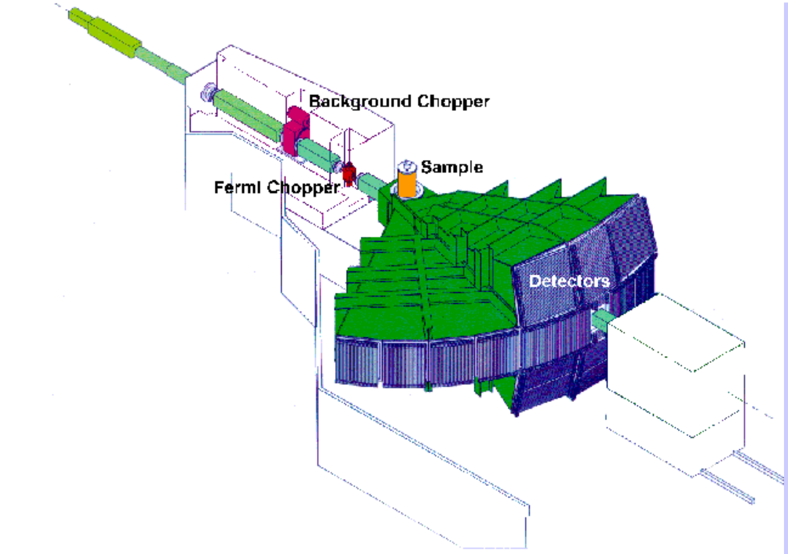
The MAPS spectrometer at ISIS is optimised to measure high energy magnetic excitations (> ~50 meV) in single crystals with energy resolution 1-5% depending on choice of monochromating chopper. The principal innovation in MAPS is the use of position sensitive detectors that provide close to continuous coverage over a large solid angle detector array in the forward direction.

Applications

- Magnetic excitations in single crystals
- Structural excitations in single crystals
- High resolution studies of non-dispersive excitations

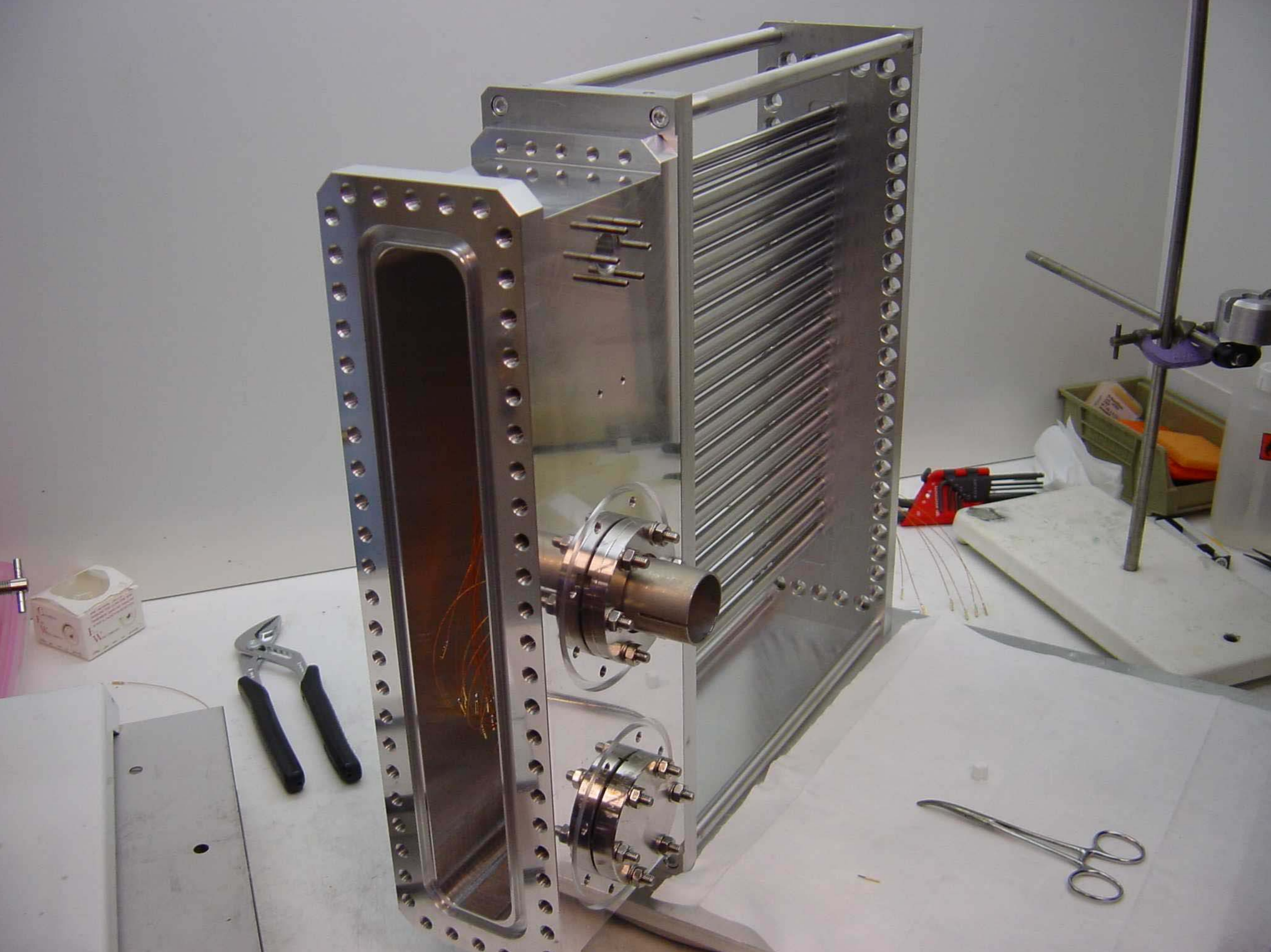
Detectors

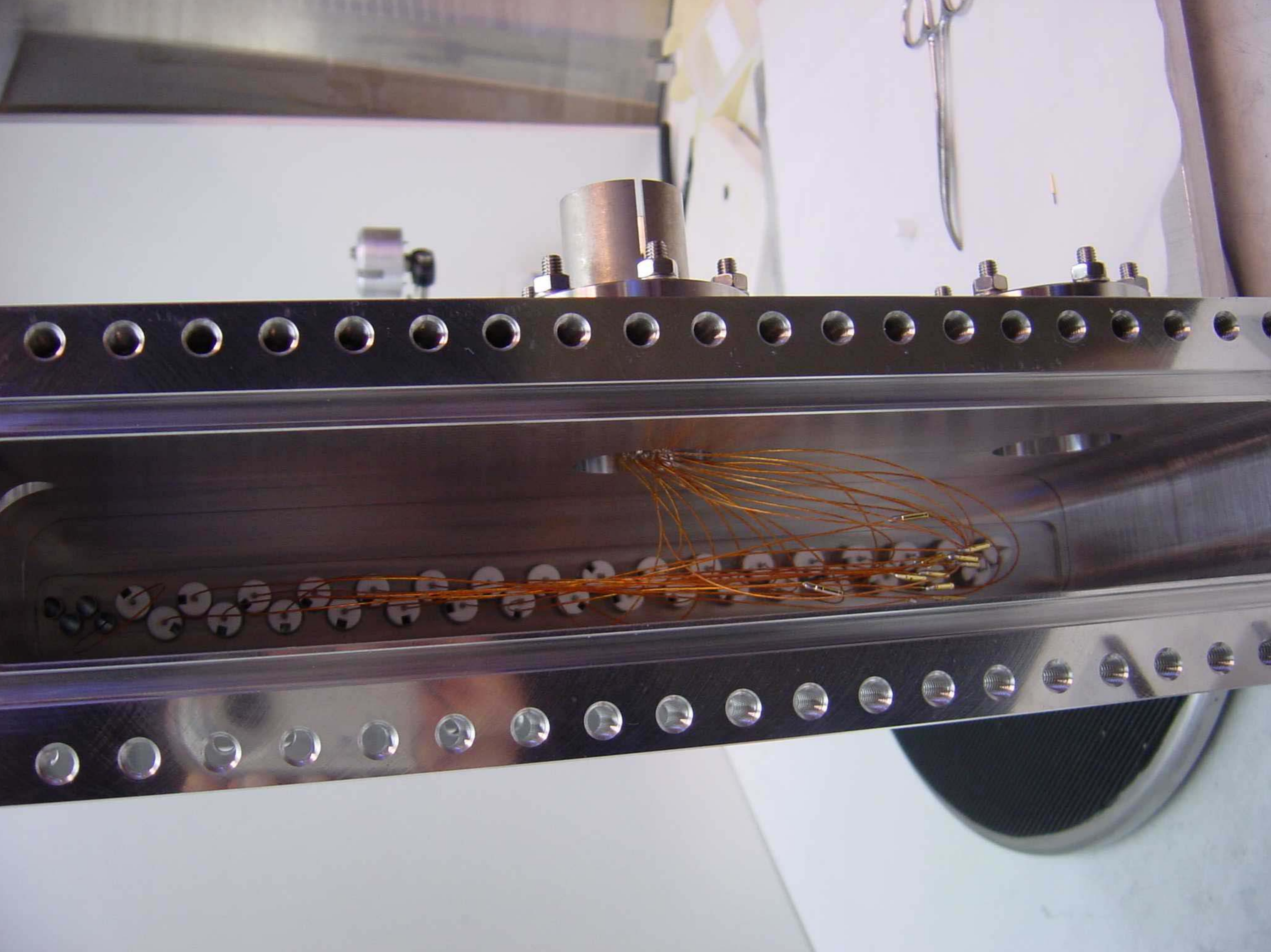
- 6 m from sample position
- approx 16m2 array of 147,456 pixel elements
- 574 Position sensitive 3He tubes (10 bar partial pressure) 2.5 cm diameter, resolution 15mm along their lengths



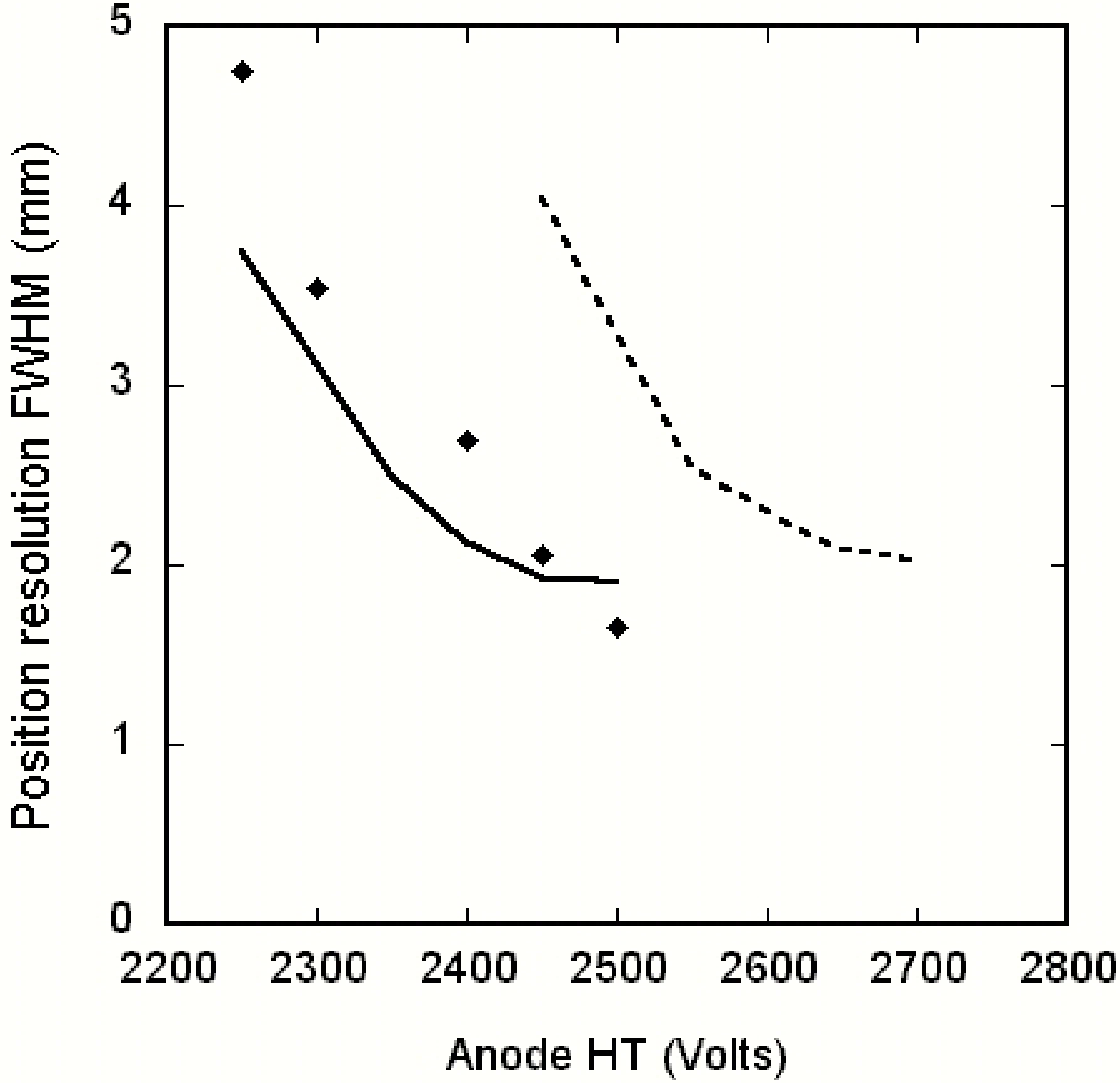

The Multitube detector
x tubes are brazed on
a common gas vessel
on both ends.

Fabrication of the MT32 prototype



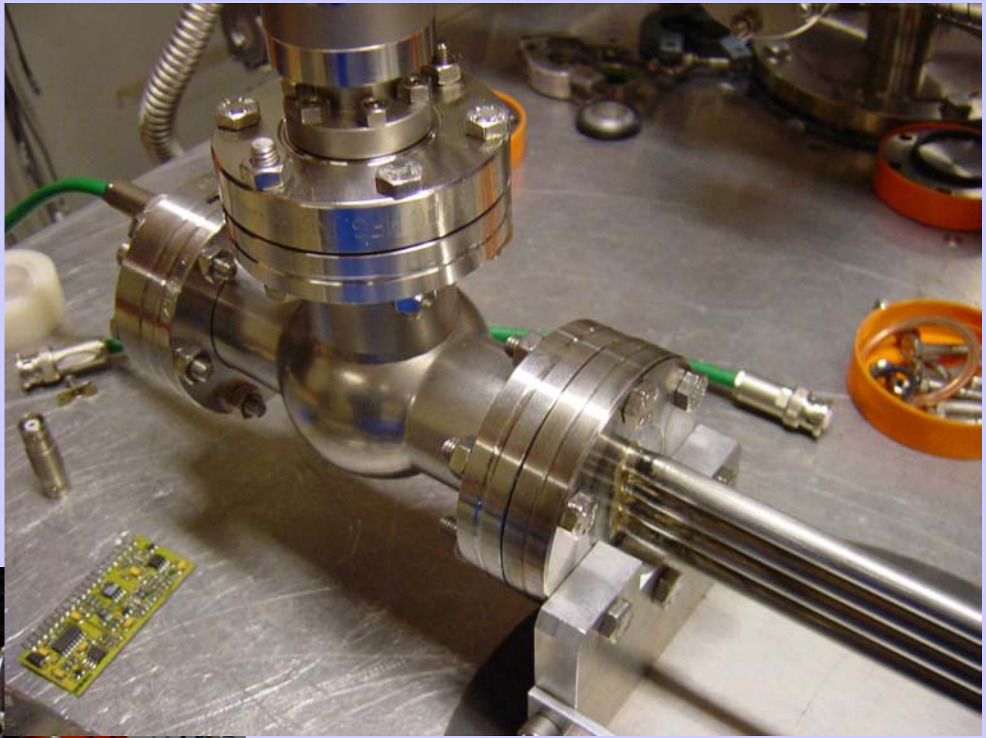


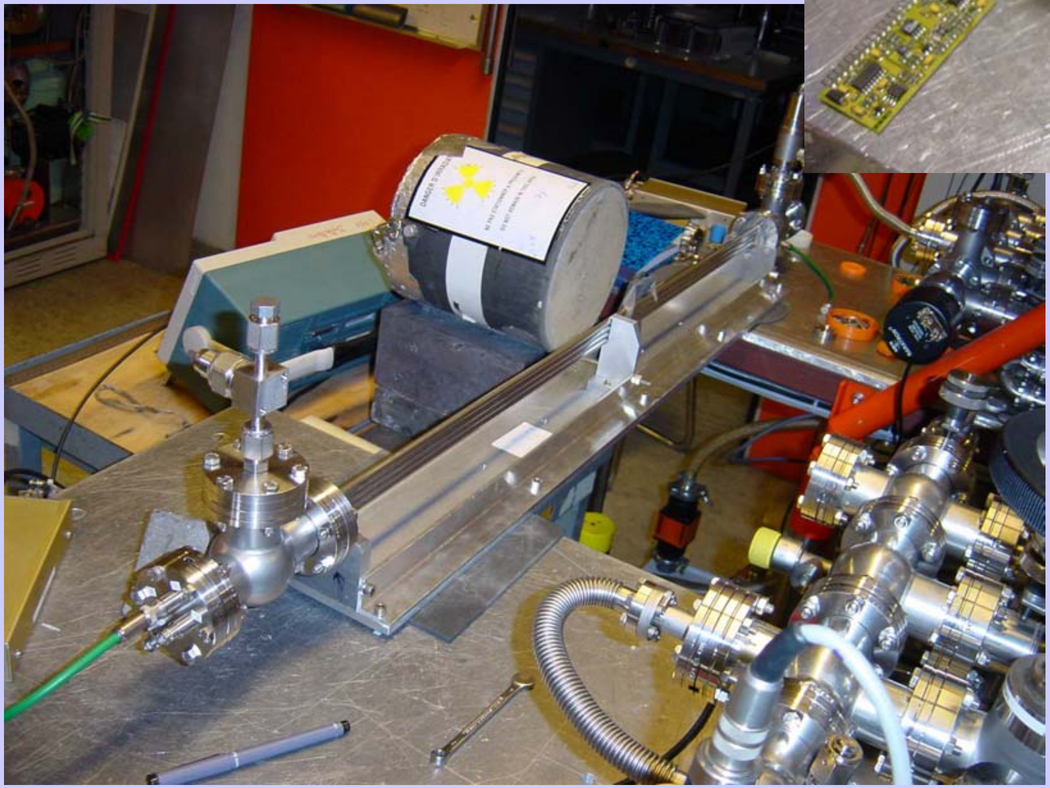
Position resolution



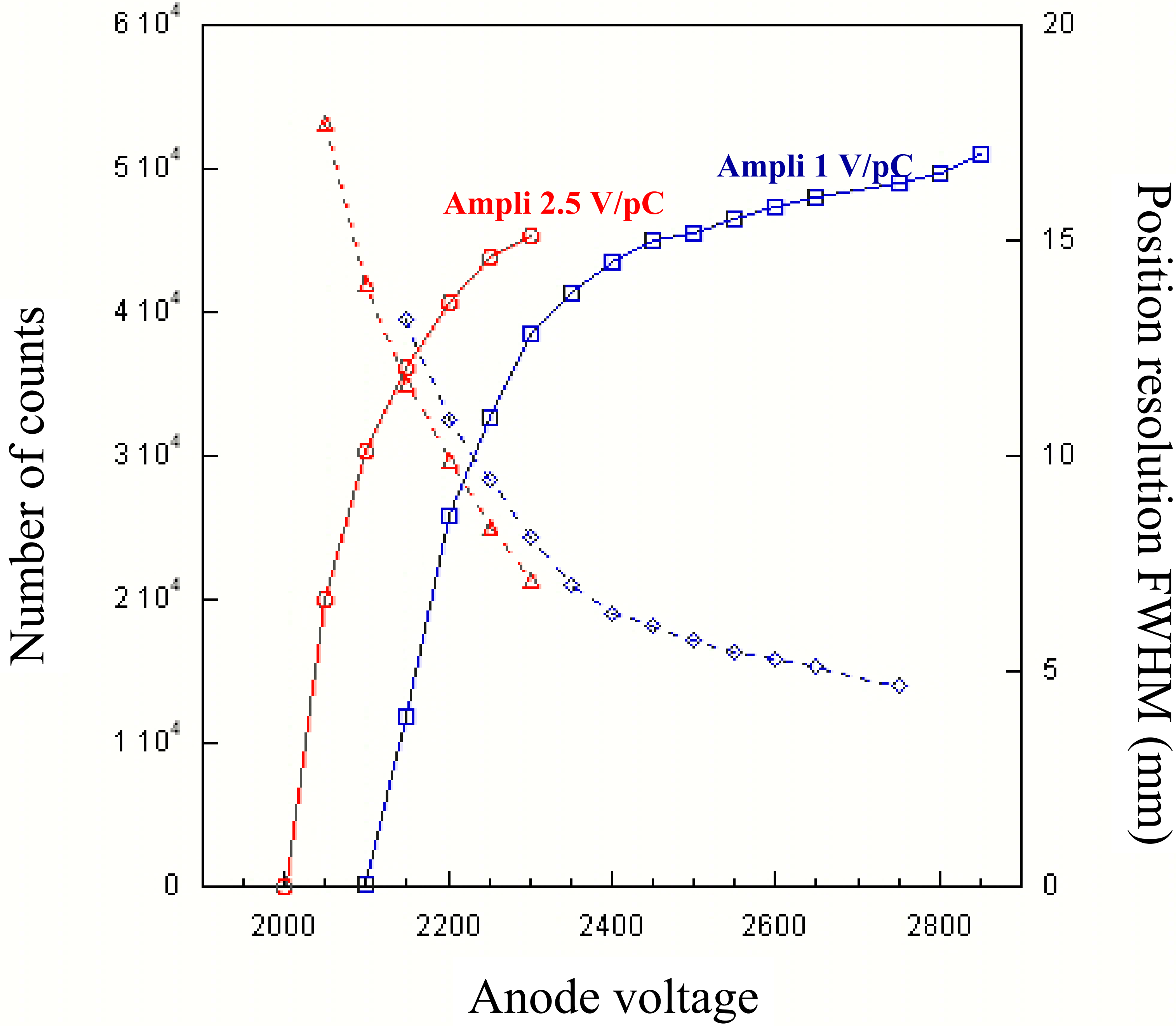
The MT4 prototype

4 tubes of 1 m long and 8 mm diameter.

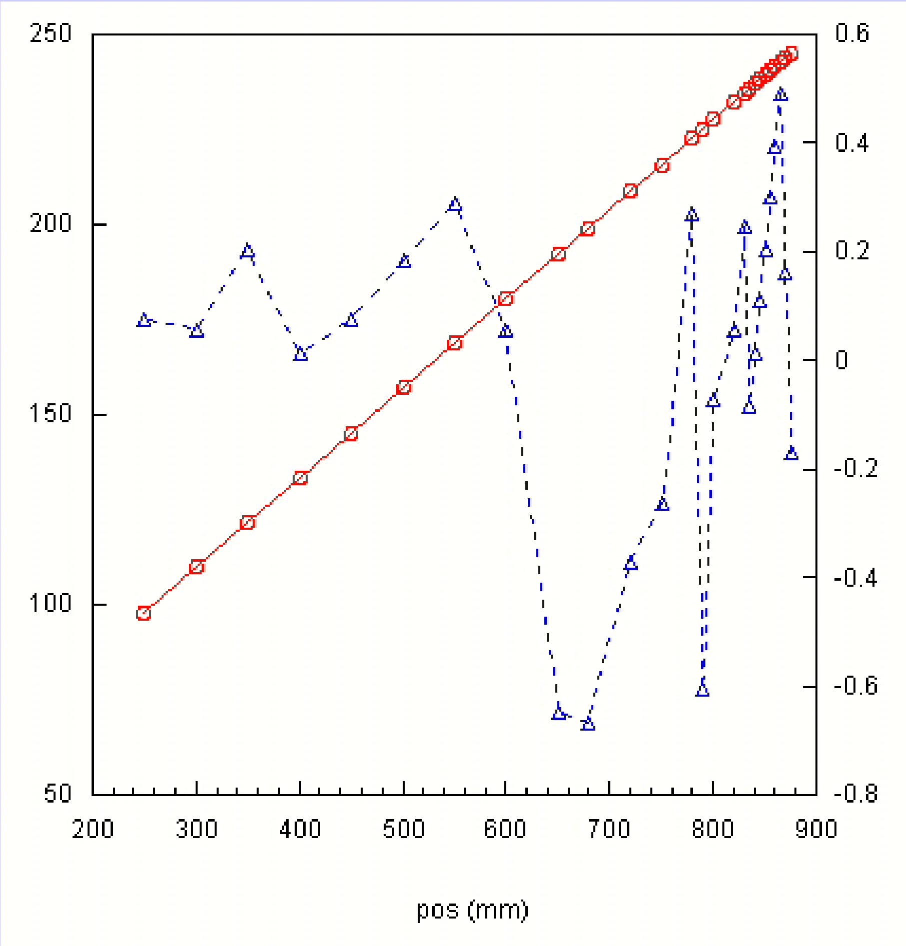




measured detection parameters = those obtained with PSCT.

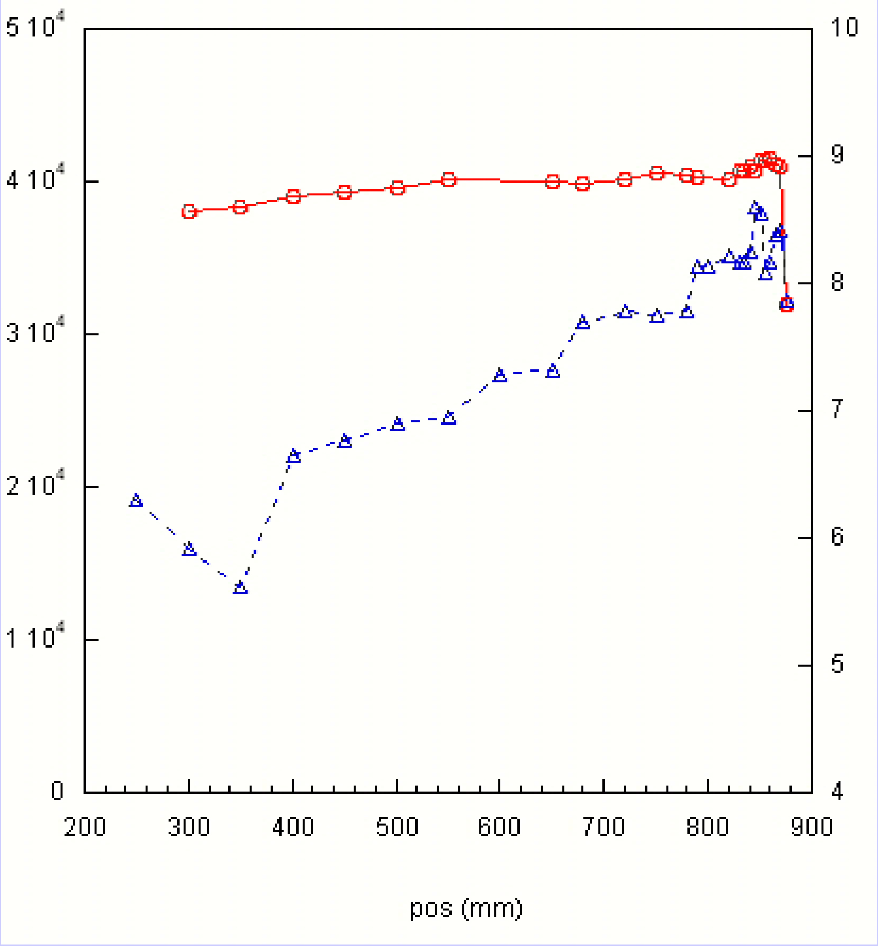


Ampli 2.5 V/pC
Ampli 1 V/pC
Number of counts
Position resolution FWHM (mm)
Anode voltage
0
1 10^4
2 10^4
3 10^4
4 10^4
5 10^4
6 10^4
2000
2200
2400
2600
2800
0
5
10
15
20



Spatial linearity

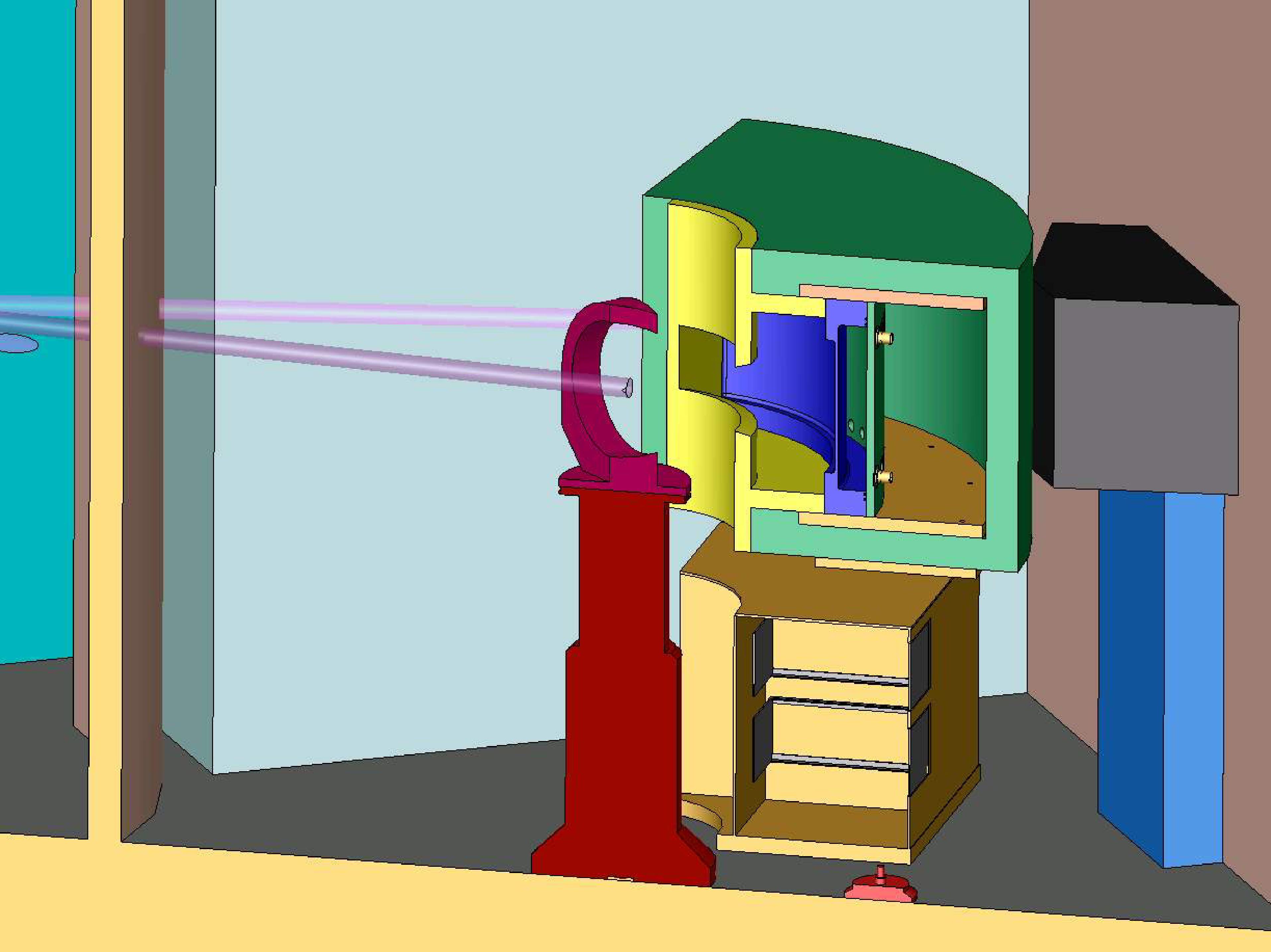
Position resolution



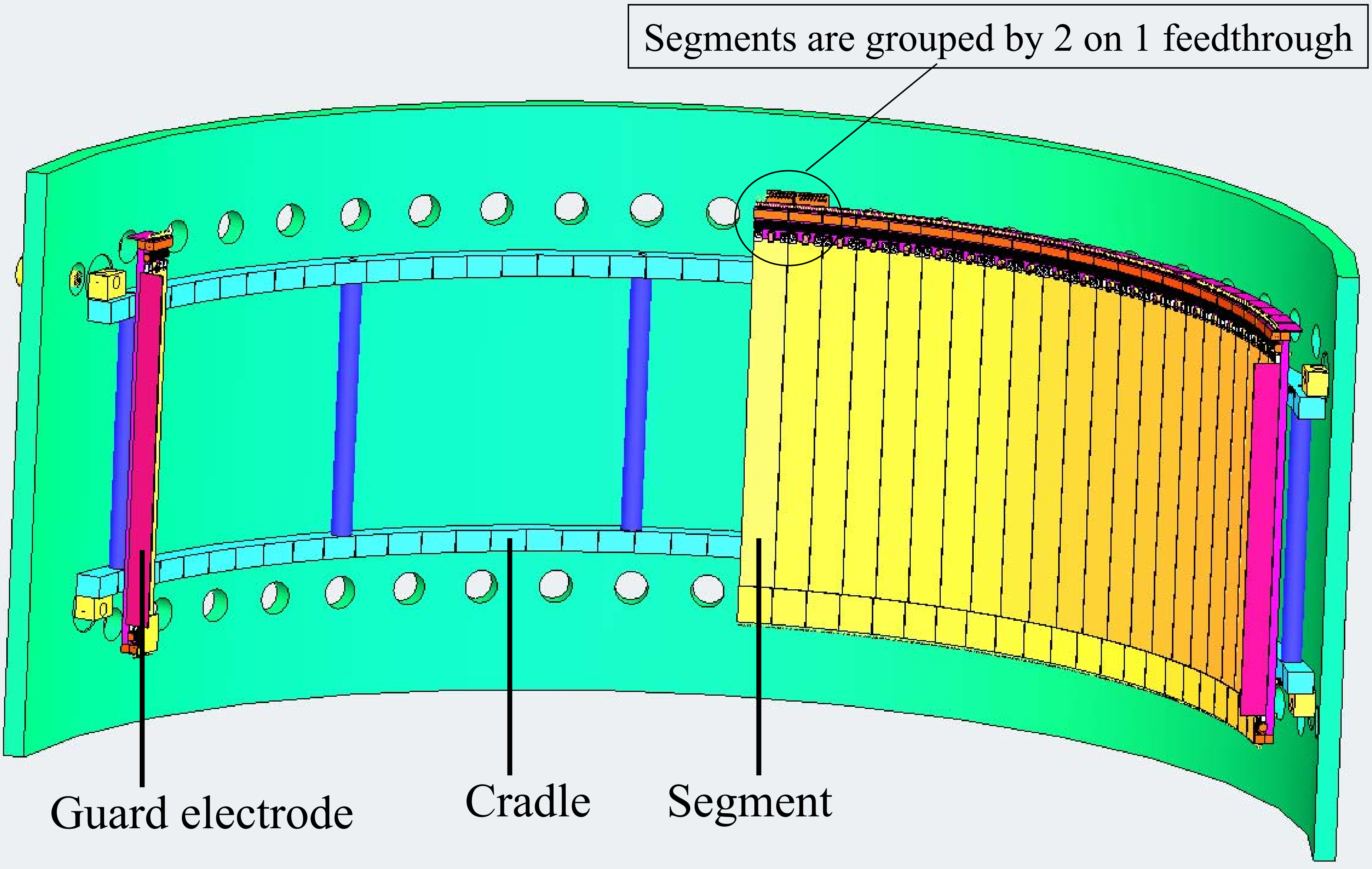
The Multitube as an alternative for the detector of the IN5 TOF spetrometer

10 curved modules, 32 tubes each, 2 m high.

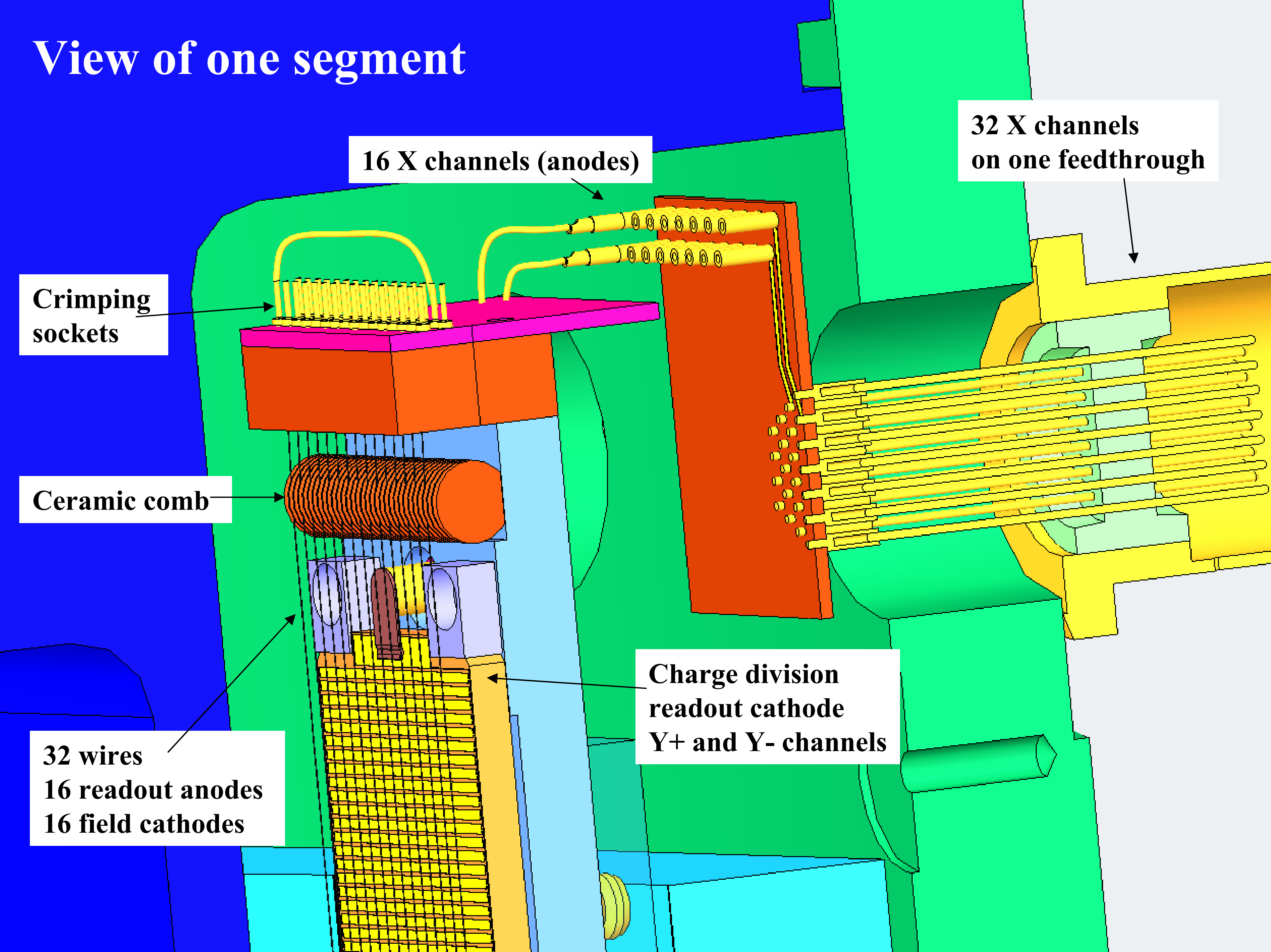
A very large angular coverage banana MWPC

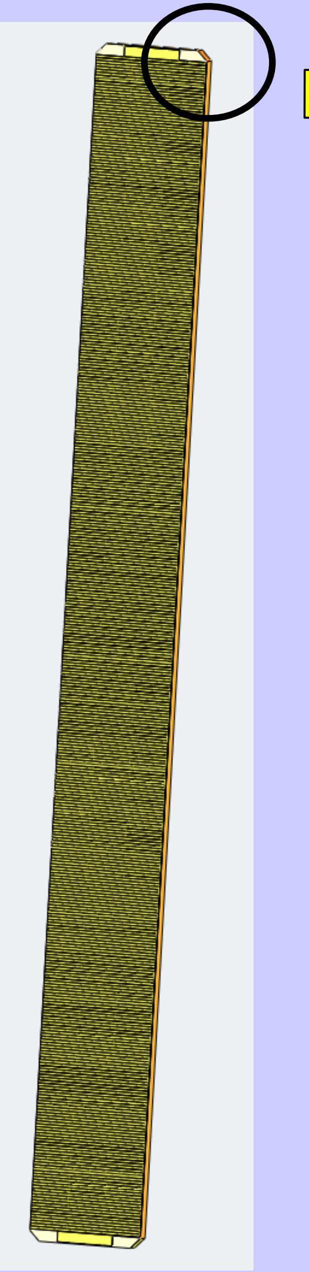


Assembling of 40 segments on one cradle

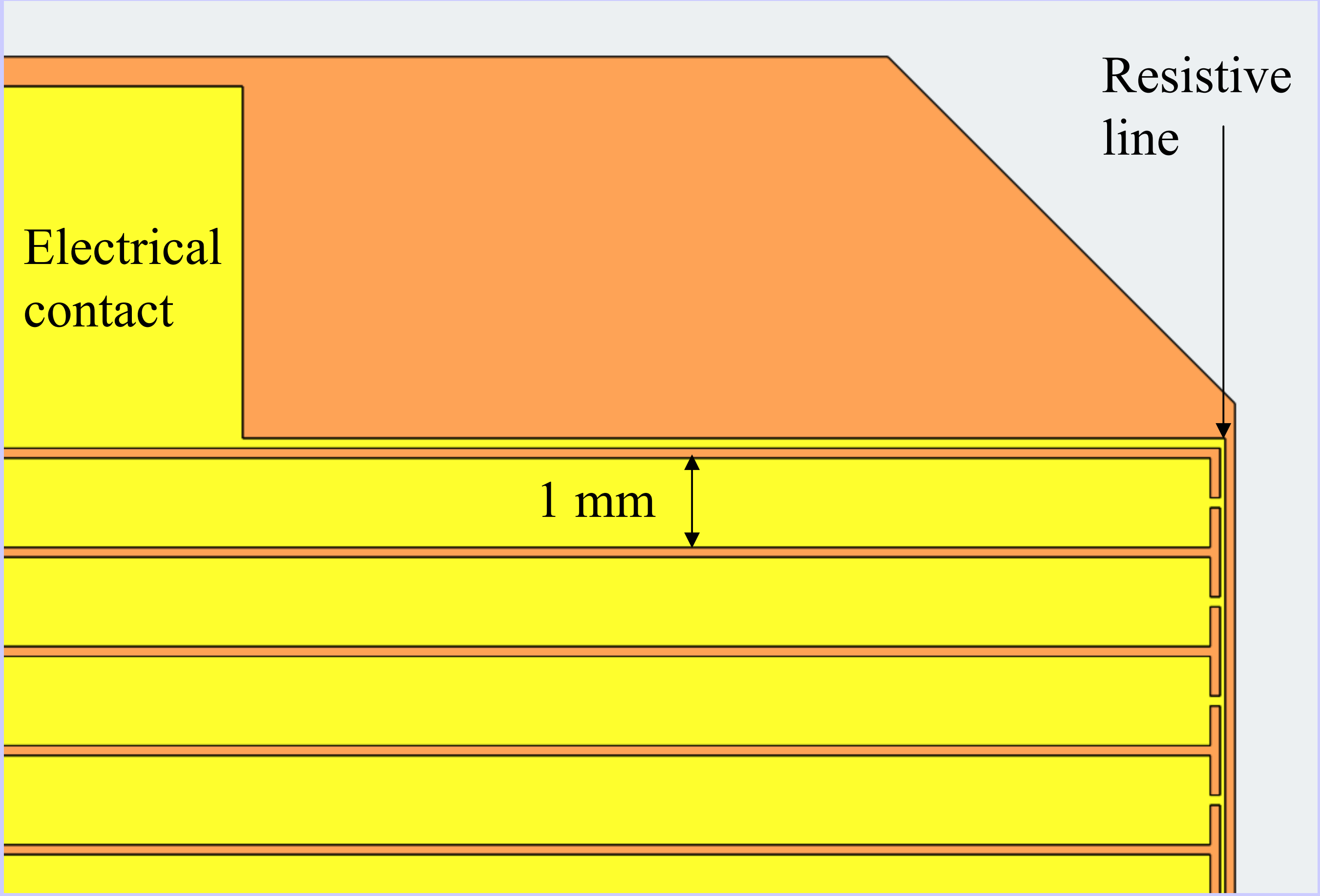


View of one segment





Cathode strips 1 mm wide
Interlinked with a resistive line of ~10 kohms
Substrat : Sodalime glass 410 mm x 40 mm x 4.8 mm
Chromium metallisation



Specifications

Radius of curvature (sample to conversion gap) : 73 cm
Active area : 40 segments of (4 cm x 40 cm)

Angular coverage : 30° X 120°

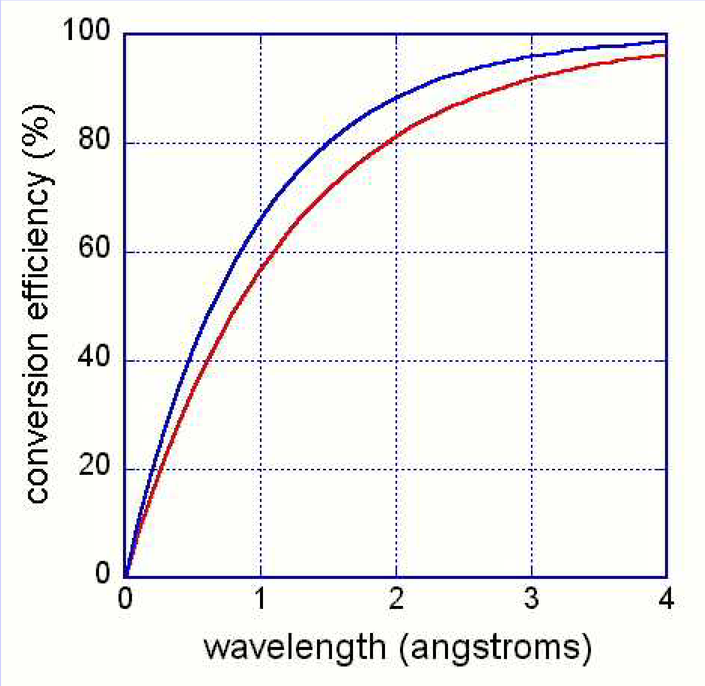
Spatial resolution : 2.5 mm in X (0.19°), 2 mm in Y (0.15°)

Gas / Conversion Gap : 4.5 bars He^3 / 3 cm

Detection efficiency @ 1 A : 60%

Total readout channels : 640 in X, 40 in Y

Counting rate : 1 MHz global and 50 kHz local



Calculation results

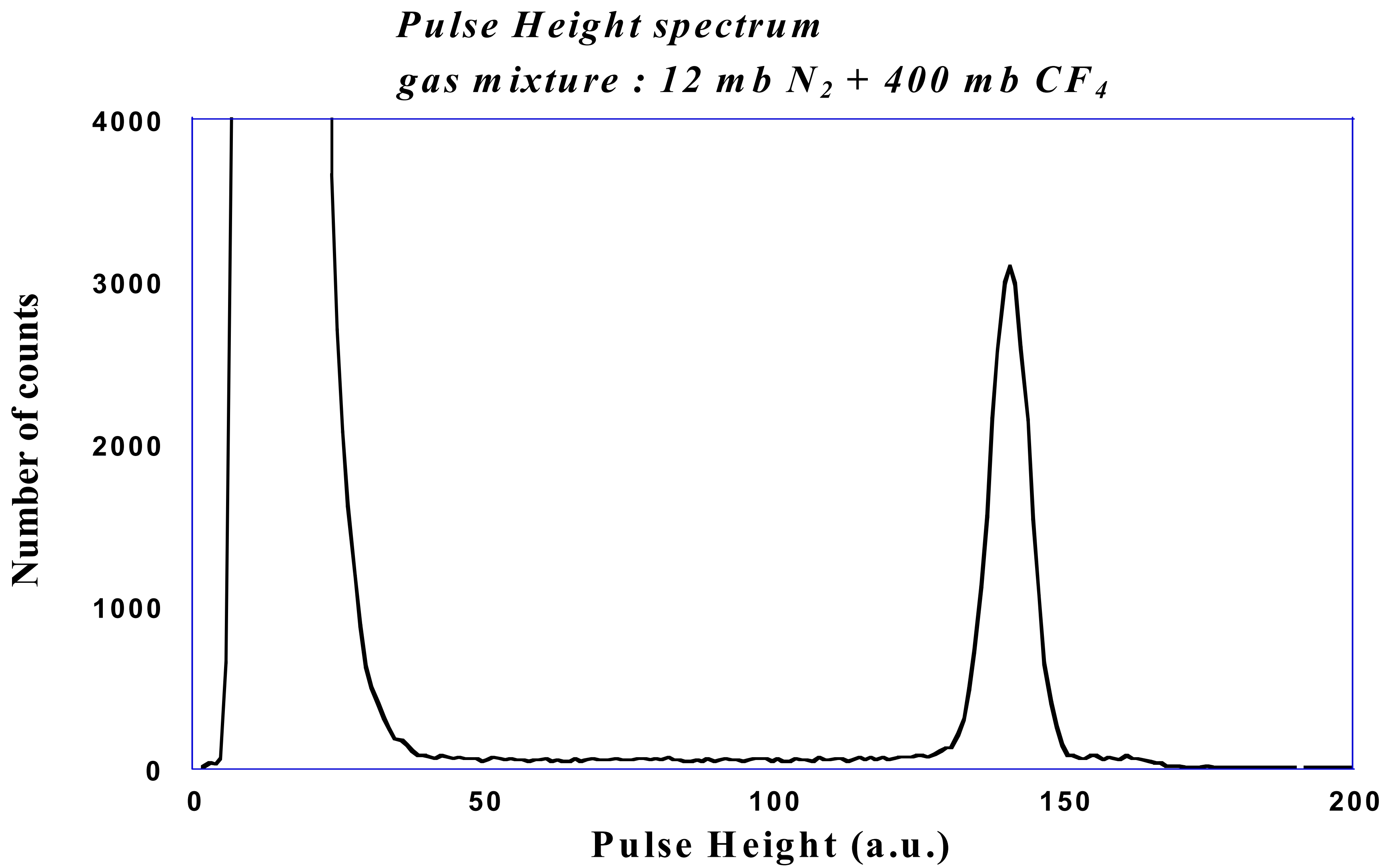
Maximum Strain values
vessel : 1.21 mm
Window : 0.68 mm

Maximum Stress value calculated on the window
37 Mpa

(Strain scale multiplied by 200)

A very low efficiency beam monitor

Convertor	N_2	^3He
Nuclear reaction	$^{14}N + n \rightarrow p + {}^{14}C + 627$ keV	$^3He + n \rightarrow p + {}^3H + 764$ keV
Capture cross section @1.8 Angstroms (mbarns)	1.8	5350
Gas pressure to obtain 10^{-5} detection efficiency in 1 cm conversion gap	100 mbars	0.07mb

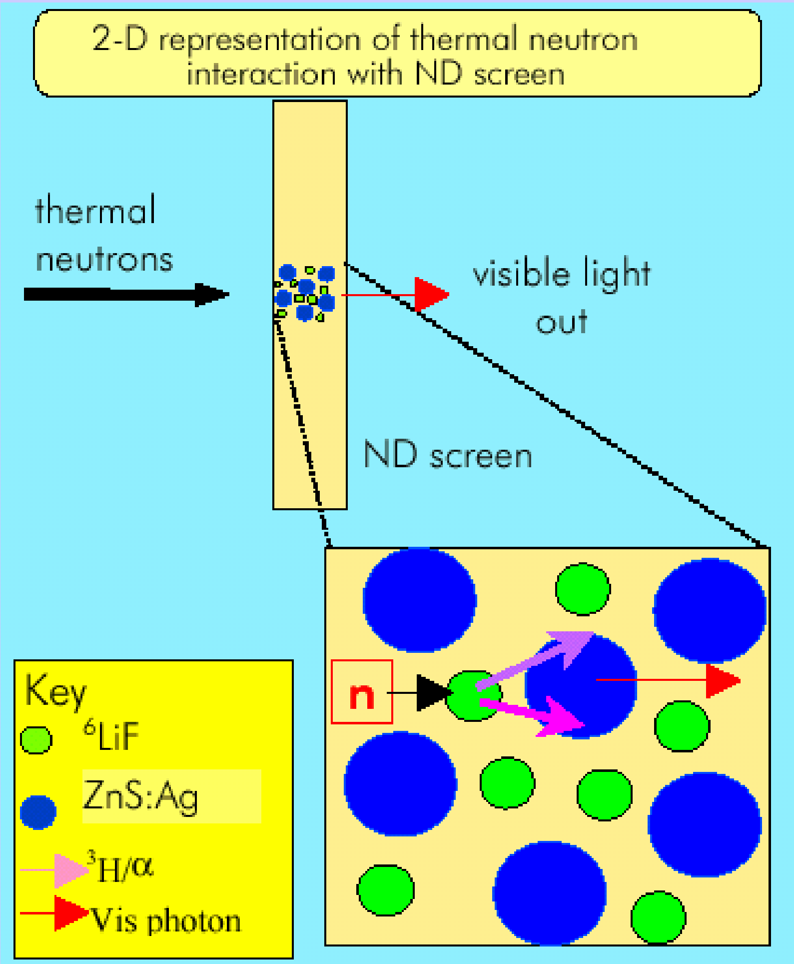


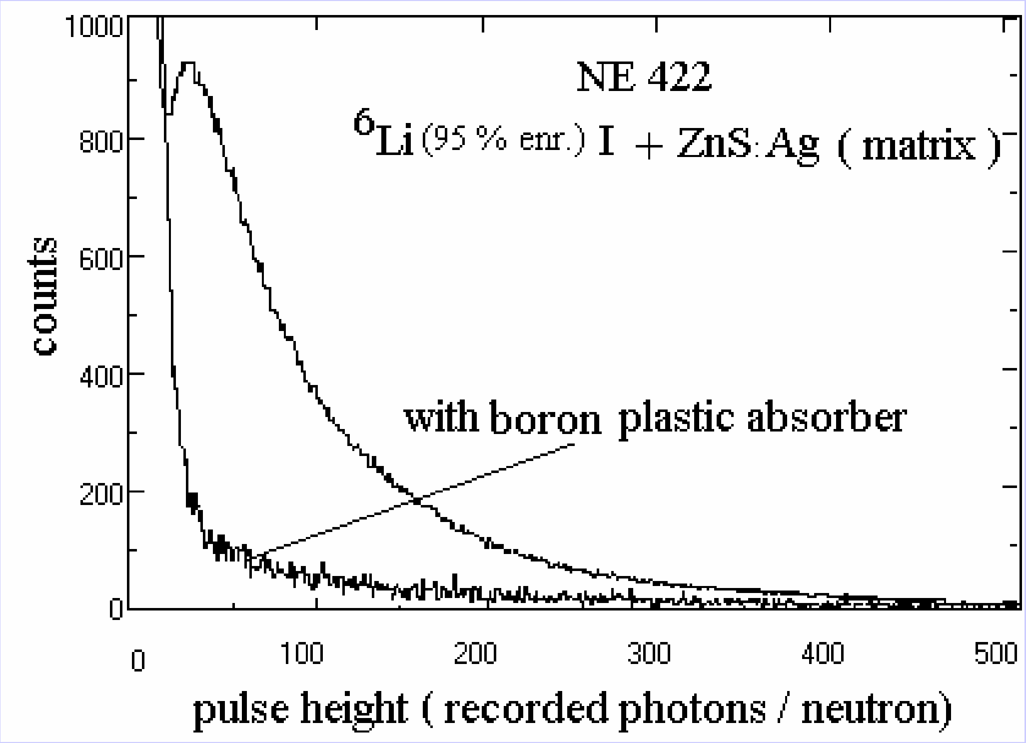
Pulse Height spectrum
gas mixture : 12 mb N_2 + 400 mb CF_4
4000
3000
2000
1000
0
Number of counts
0
50
100
150
200
Pulse Height (a.u.)

Scintillators

ZnS:Ag/Li6F scintillator

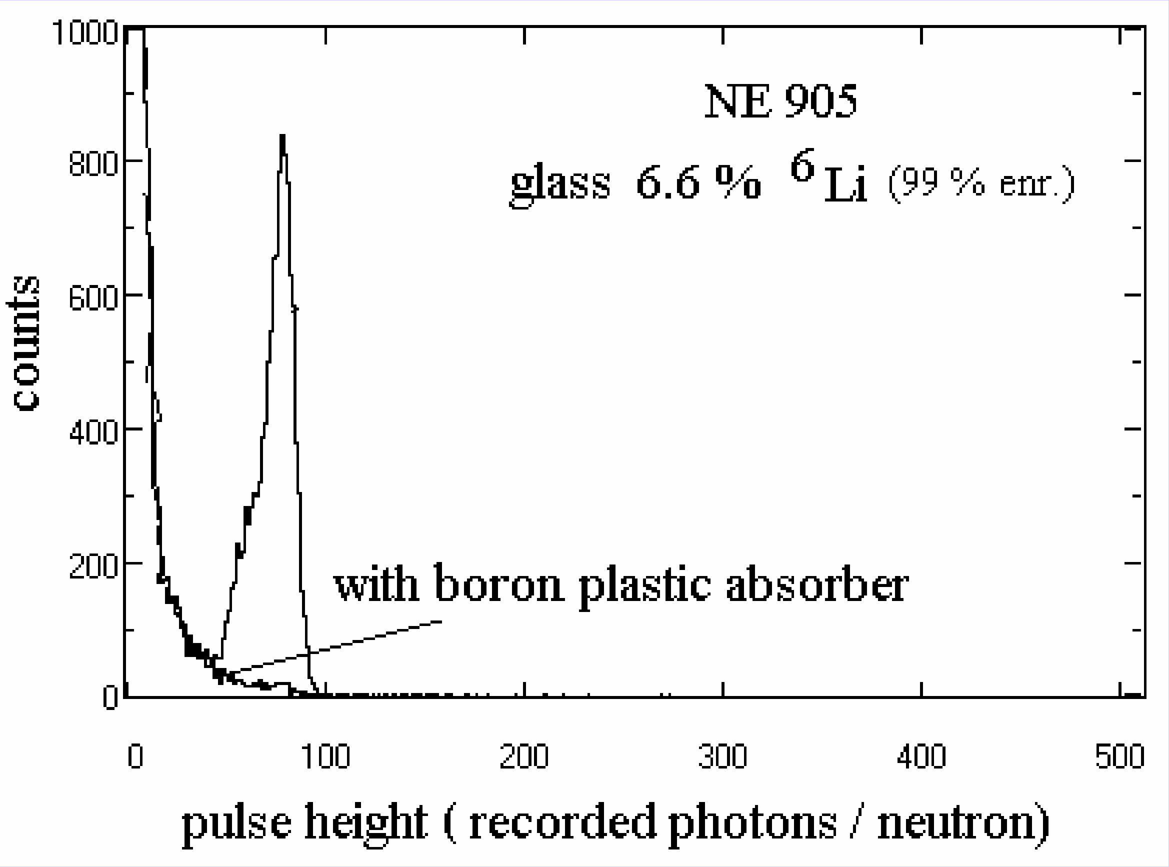
Thickness : 0.42 mm
Decay to 10% : 80 μs
Emission spectrum peaked at 450 nm
~ 160.000 photons/ neutron



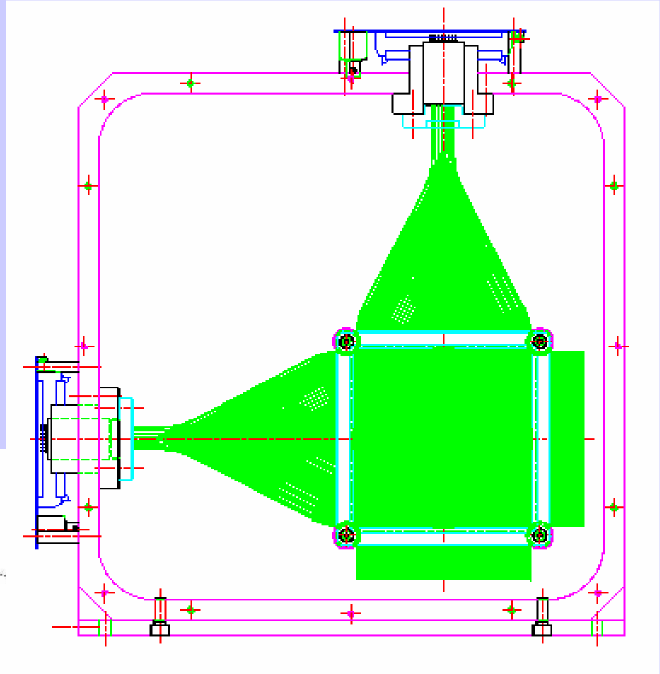


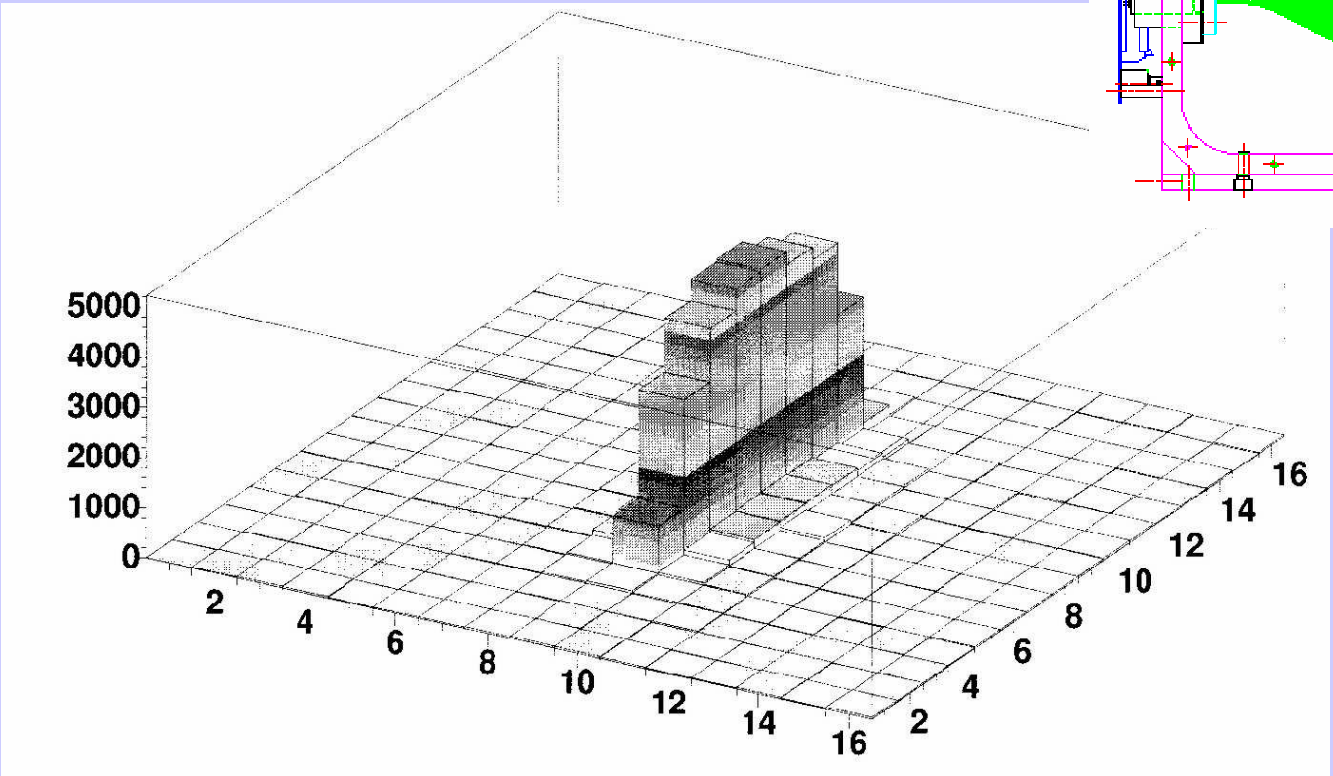
Li Glass scintillator (GS20)

Thickness : 0.5 or 1 mm
decay to 10% : 60 ns
Emission spectrum peaked at 395 nm
~ 7.000 photons/ neutron



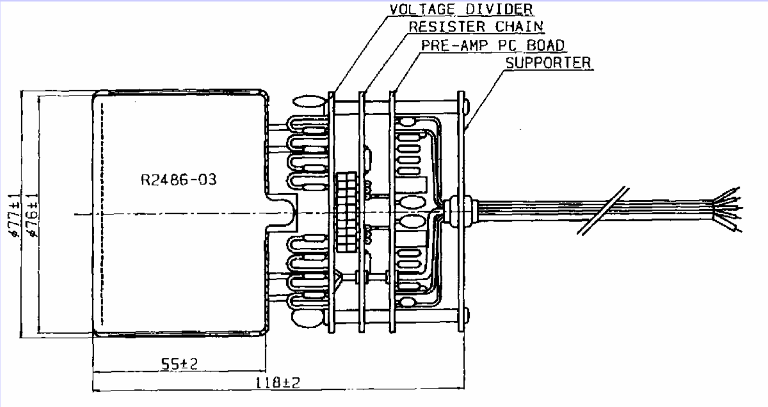
Scintillator : ZnS:Ag/Li6F
0.5 thick square WLS fibers Y11
4x4 multi-anode PM





Position sensitive PM : Scintillator directly in contact with the PM

\+ : cost and gamma discrimination
\- : counting rate



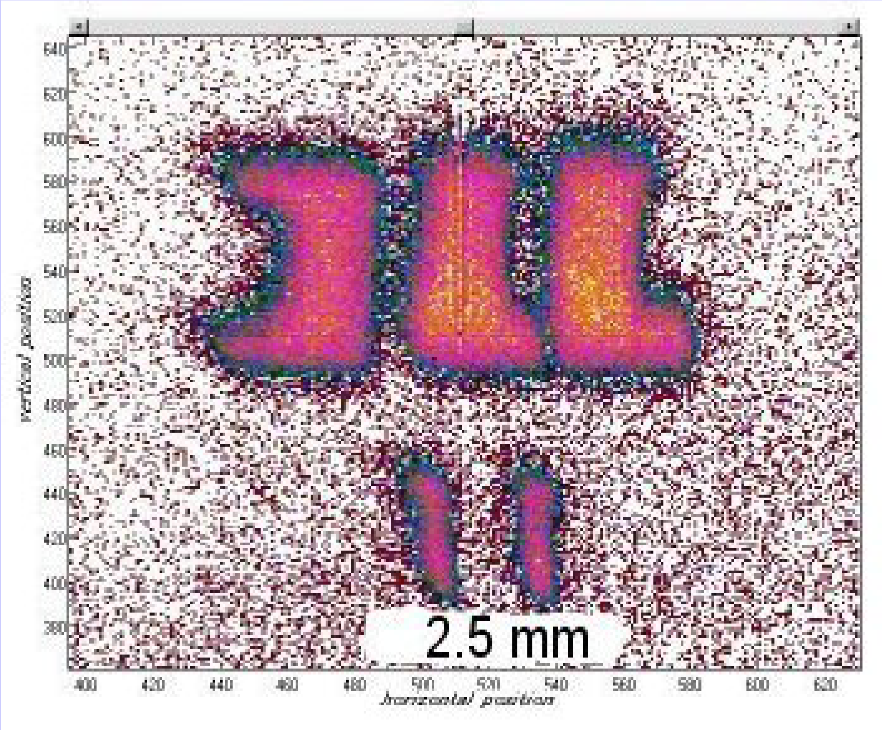
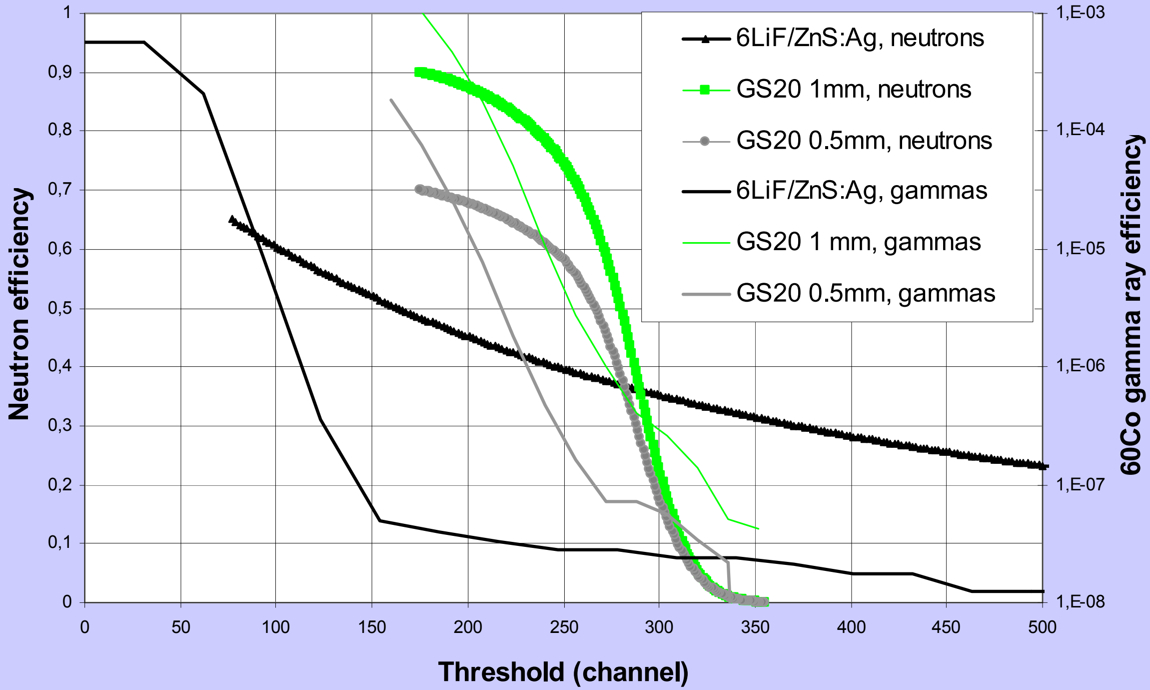


Image measured with a Cadmium mask in front of the scintillator-PM detector.

Position resolution : 0.6 mm (FWHM)



Scintillator	Neutron detection ε_n	^{60}Co Gamma sensitivity ε_γ
^{6}LiF/ZnS:Ag	52 %	5.10^{-8}
GS20 (0.5 mm)	60 %	2.10^{-7}
GS20 (1 mm)	78 %	1.10^{-5}

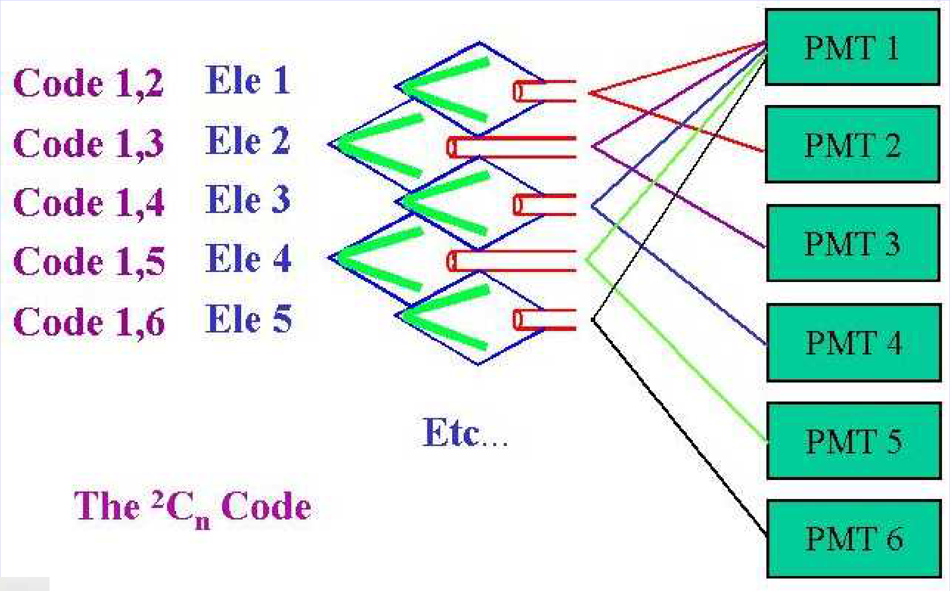
GEM - fibre coupled zinc sulphide scintillator detectors

GEM is designed to be a high intensity, high resolution neutron diffractometer for structural studies of disordered materials and crystalline powders.
The detectors will cover a very wide range in scattering angle from below 5° to170°.

When GEM is completed …

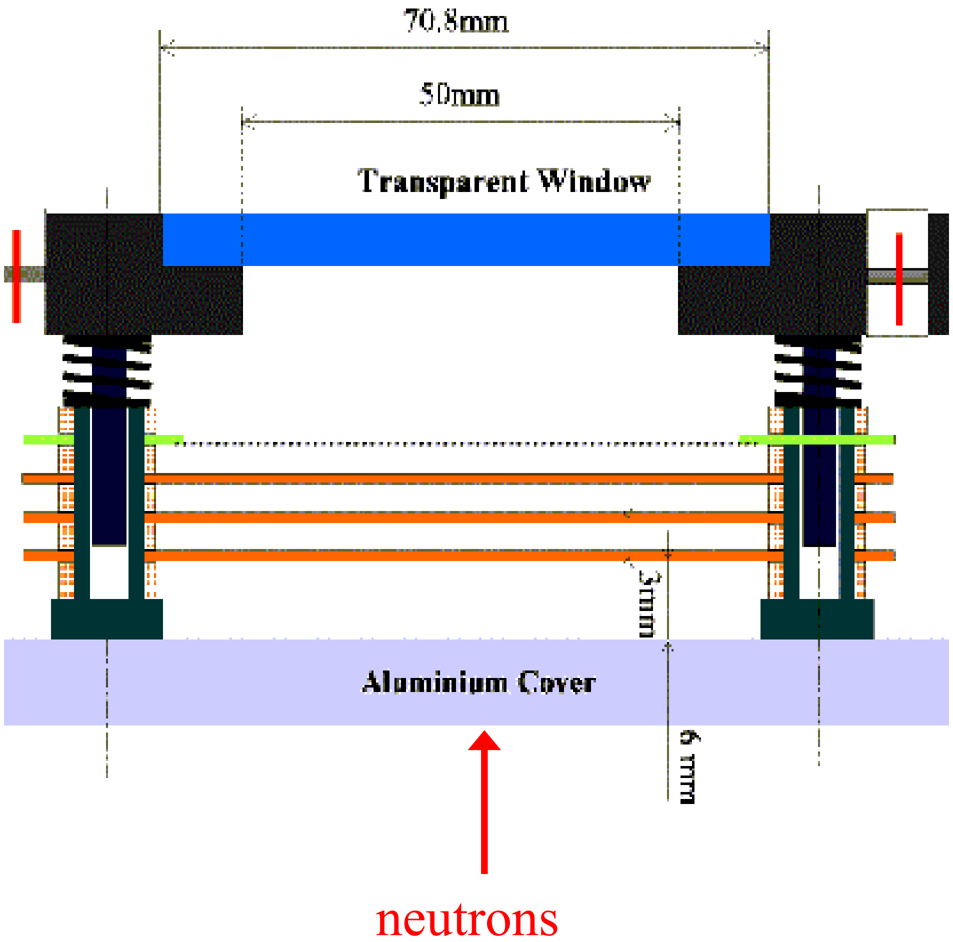
~3.5 steradians
Area 10 m2
6550 detector elements in 75 modules.
660,000 individual optic fibres, whose total length will be about 350 kilometres.

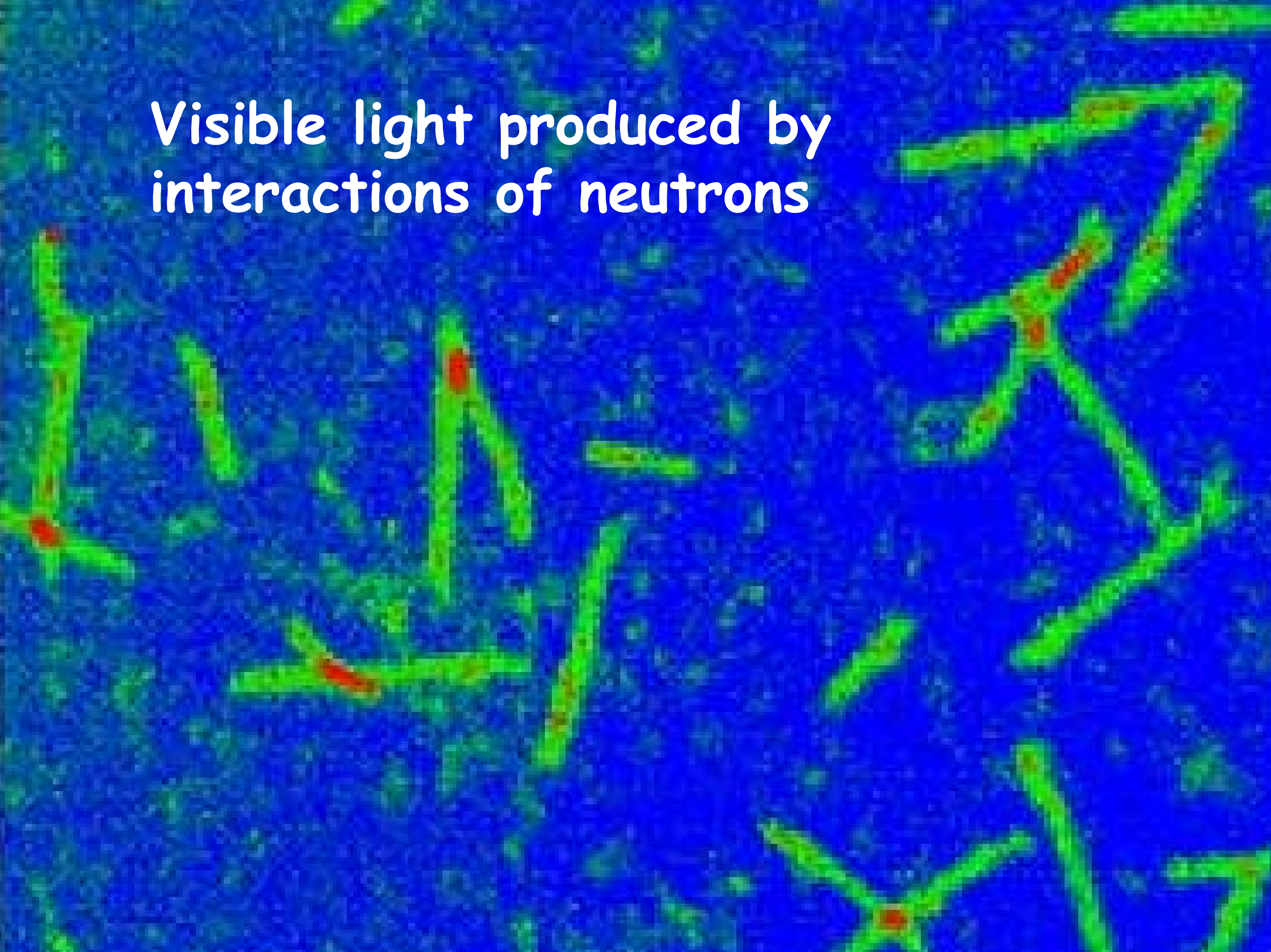
X resolution 5 mm
Y resolution 200 mm
detector efficiency (60Co) 10-7
intrinsec background 12 c/element/hr
pulse pair resolution 2.5 μs
stability < 0.1 %/°C



120 elements
^2C_n coding to 16 PMT
coincident pairs of PMT outputs determine origin of a single neutron interaction

Active gas Scintillators (GEM + CCD camera)




Visible light produced by
interactions of neutrons

- The reliability of MSGC detectors is now established. They do not provide a significant improvement as compared to MWPC.

- For continuous sensitive area larger than 20 cm x 20 cm, good position resolution is obtained with MWPC.

- PS Counter tubes, and similar detectors, will be extensively used in SNS for several large area instruments with moderate position resolution. The Multitube provides an effective way to decrease the fabrication cost.

- Scintillator detectors with counting or integrating devices are an alternative solution to gas counters